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**AMBIENT AIR SAMPLING
FOR PCDD/PCDF
NEAR TWO PULP MILLS
IN NORTHERN ONTARIO**

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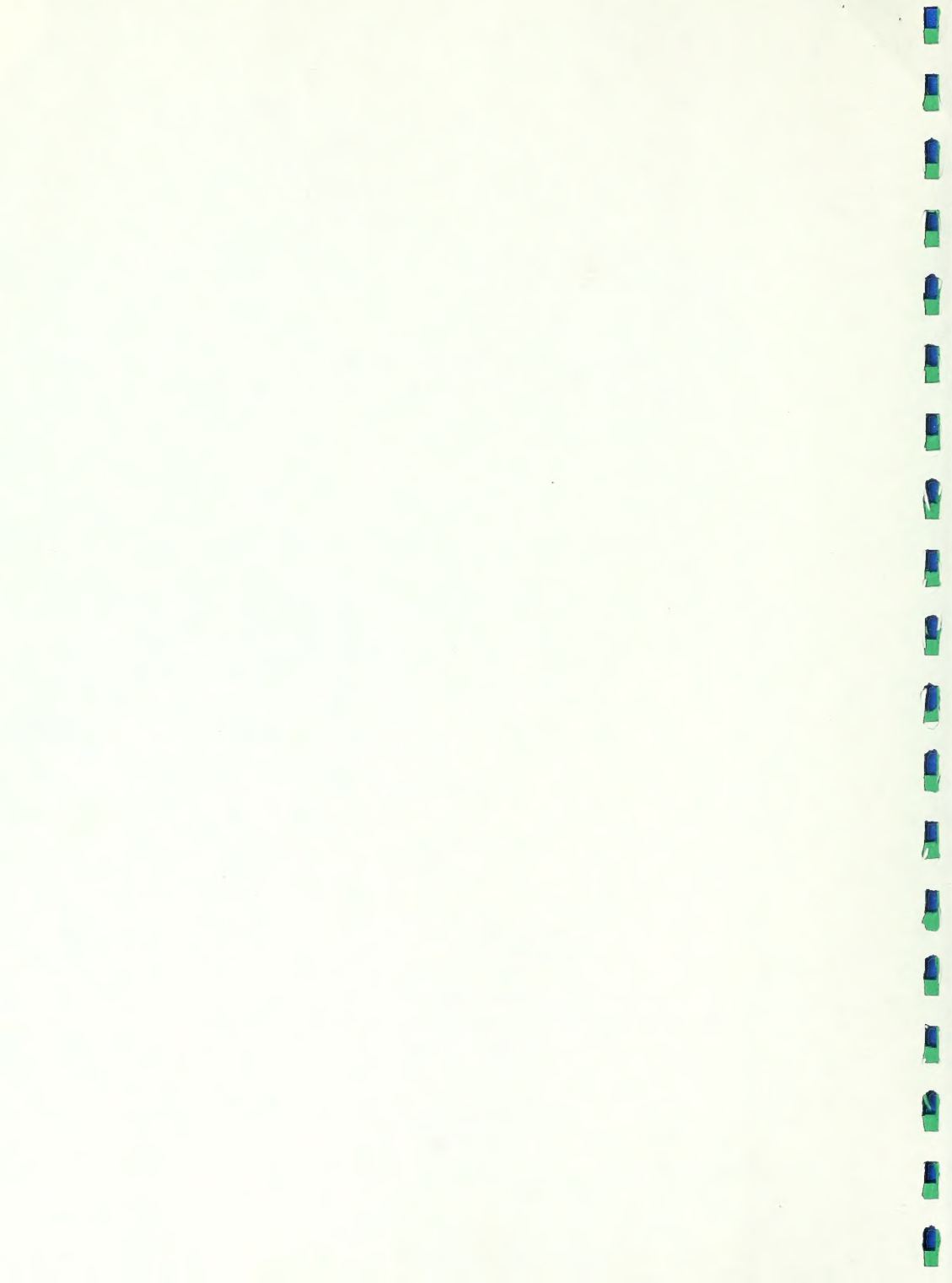
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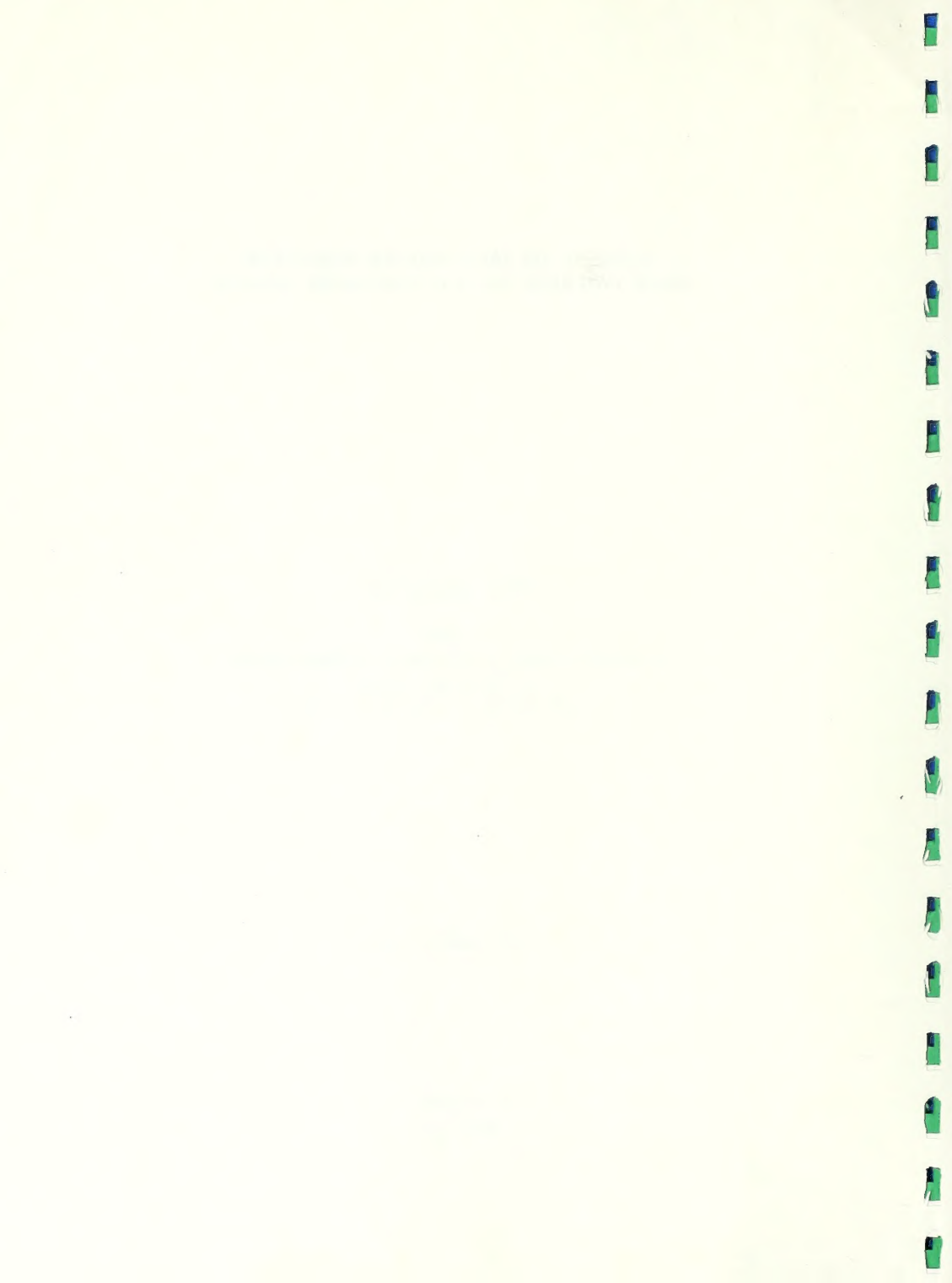
AMBIENT AIR SAMPLING FOR PCDD/PCDF
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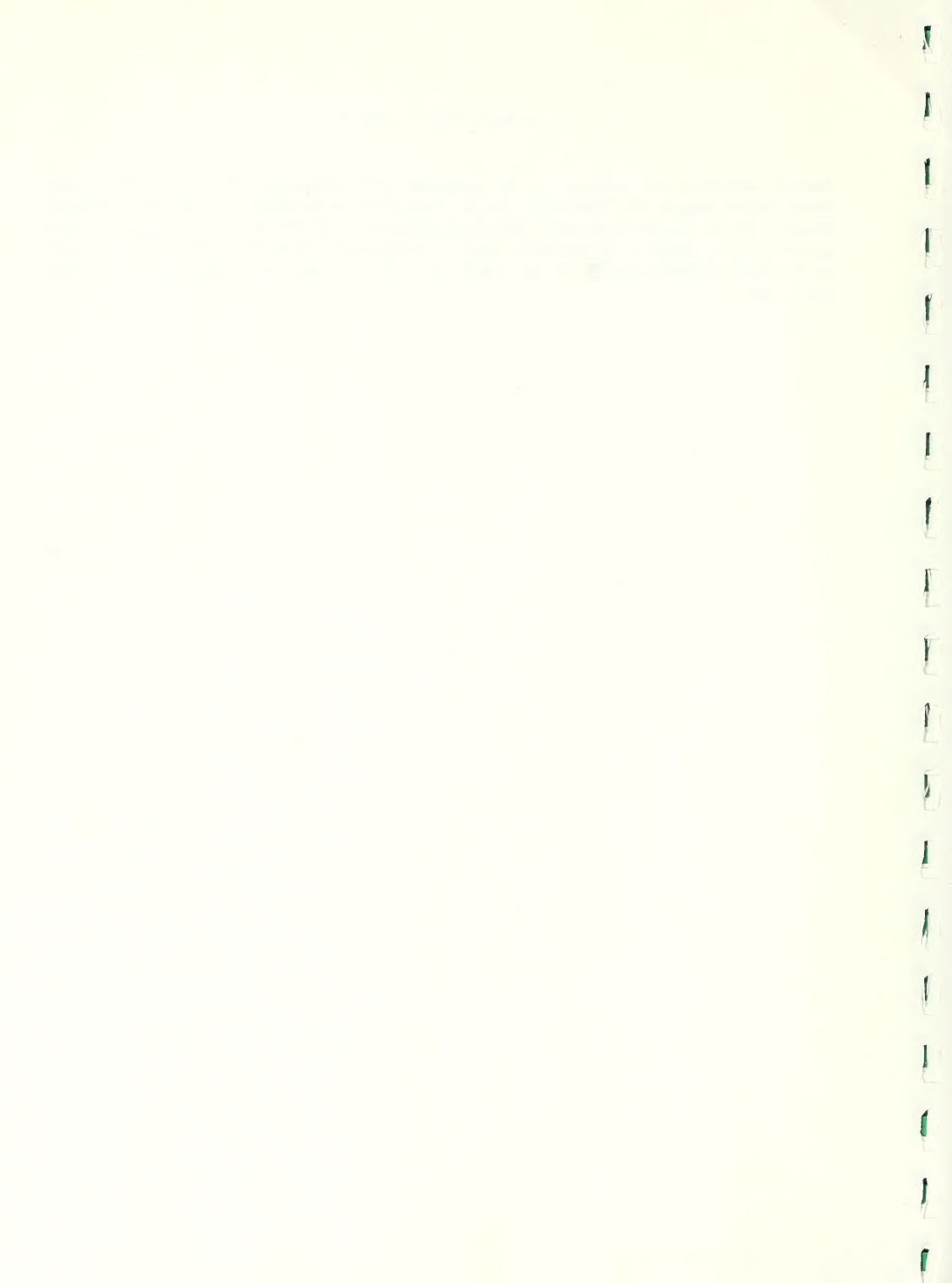
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INTRODUCTION

It is generally well accepted that pulp mills are a source of polychlorinated dibenzo-p-dioxins (PCDD) and dibenzofurans (PCDF) (e.g. 1-3 and references therein). Historically, the discharge of these toxic chemicals has created water quality problems rather than air quality degradation. However, the burning of sludge of bleached mill origin is not uncommon (4 and references therein) and this practice may lead to somewhat higher PCDD/PCDF concentrations in the local airshed.

Based upon requests from the Chiefs of Air Quality Assessment in Northwestern Region (NWR) and Northeastern Region (NER) a one-year ambient air monitoring program was undertaken to determine whether there exist detectable levels of PCDD/PCDF in ambient air in the vicinity of pulp mills, and, if these compounds are detected, whether their presence can be attributed to the pulp mills.

Two sites were selected for ambient air monitoring; one in NWR near James River-Marathon Inc. in Marathon; and one near Malette Kraft Pulp in Smooth Rock Falls (Fig. 1). Each site is approximately 1/2 km from the nearby mill. There are no other potential sources of PCDD/PCDF at these two sites. A summary description of the two mills is provided in Table I.

FIGURE 1. Monitoring site locations in northern Ontario.

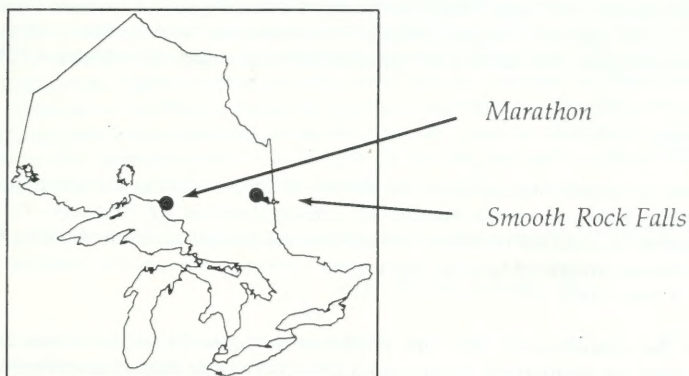


TABLE I. Basic characteristics of the two pulp mills involved in this study.

	James River-Marathon	Malette Kraft Pulp
Mill Type	Bleached Kraft	Bleached Kraft
Sludge Treatment	Landfill	Incineration
Wood Type	Primarily softwood (94%)	Softwood
Design Capacity	535 kt/day	330 kt/day

For most mills, the bleachery effluent bypasses the primary clarifier (e.g. James River-Marathon Inc.), however, for Malette Kraft Pulp some of the bleachery effluent goes through the primary clarifier. It is for this reason that the Malette mill *may* represent a worst-case scenario: some bleachery effluent passing through the primary clarifier and incineration as the preferred sludge treatment.

Generally, the formation of PCDD/PCDF is lower in sulphite pulp mills than either hardwood or softwood kraft pulp mills and is lower in hardwood than softwood kraft pulp mills (1).

SAMPLING & ANALYSIS

Ambient air samples were collected using a high-volume air sampler modified to accept a polyurethane foam (PUF) vapour trap behind a teflon-coated glass fibre particulate filter. Further details are available elsewhere (5-7). Air samples were collected for 48 hours beginning once every 28 days. In NWR, 13 samples were collected, however, in NER only 11 valid samples were collected (the two missed samples were caused by i) a frozen sampling pump; and ii) poor analytical spike recoveries).

Collected samples were spiked with $^{13}\text{C}_{12}$ -TCDD, -PCDD, -HxCDD, -HpCDD, and -OCDD and then Soxhlet extracted with toluene overnight. Extracts were then concentrated by rotary evaporation and cleaned up using a modified Dow procedure. Analysis was by GC/MS/MS on a Finnigan TSQ70 in the reaction ion monitoring mode. More detail may be found elsewhere (5,7). Towards the end of the one-year sampling effort, the Laboratory Services Branch began providing toxic congener analysis. The method is virtually identical to U.S. EPA Method 1613.

RESULTS & DISCUSSION

Results from the ambient air monitoring program are shown in Table II. Concentrations are in picograms per cubic metre followed by the number of isomers detected (in brackets). If the number of isomers detected is zero, the reported concentration is the detection limit. Only the congener group total data are presented because there were so few isomer specific analyses (1 sample from NER and 3 from NWR).

Summary statistics for the concentration data are presented in Table III for Marathon and Smooth Rock Falls and also, for comparison purposes, for Dorset, Toronto Island, and Windsor. Note that the summary statistics for the last three sites are based on long-term monitoring results (Aug/Sep 1988 to Dec 1991 inclusive).

Total toxic equivalents for Marathon and Smooth Rock Falls are presented in Table IV. The calculations were made following Birmingham (8). Also shown in Table IV are the mean, maximum, and minimum total toxic equivalents for Marathon, Smooth Rock Falls, Dorset, Toronto Island, and Windsor. Again, the results for the last three sites are based on a long-term monitoring effort. If the 24-Jan-90 sample from Marathon is not included, the mean for that site drops to 0.02 pg/m³ and the maximum drops to 0.07 pg/m³. These numbers are similar to the long-term results from Dorset although they are still higher than results from Smooth Rock Falls.

Figures 2.i through 2.xii show the Marathon area and the 48 hr wind rose data for each sampling

period. Wind rose information for the November 27/28 sample is not available due to equipment failure. Figures 3.i through 3.xi present the same information for Smooth Rock Falls. Kapuskasing wind speed and direction were used for the Smooth Rock Falls site (Kapuskasing is approximately 60 km WNW of Smooth Rock Falls).

Figure 4 shows 48 hr back trajectories at the surface for Marathon. Trajectories are shown beginning from the middle of the first 24 hours of sampling and also beginning from the middle of the second 24 hours of sampling. Back trajectories at the surface for Smooth Rock Falls are shown in Figure 5. These trajectories begin from the end of the second day of sampling.

Only for some congener groups do concentration levels exceed 1 pg/m^3 and even then, only for the January sample collected at the Marathon site. Surface back trajectories for the sample in question suggest either the pulp mill as a source or the Detroit/Windsor area depending upon which air parcel is examined: the one beginning during the second day of sampling (---x---x---) or the one beginning during the first day of sampling (--o----o--). Examination of the 850mB level back trajectory (not shown) possibly supports the pulp mill as a source but not the Detroit/Windsor area. The wind rose constructed for this sample (Fig. 2.i) does not provide concrete corroboration. Over the course of the 48 hr sampling period, the wind blew from the pulp mill to the sampler for only approximately 15% of the time. Remember, also, that sludge disposal at this mill is by landfill, *not* incineration.

Ambient levels of PCDD/PCDF were only high (relatively) for one sample at one site, however, wind roses and back trajectories for other samples at both sites are likewise inconclusive. Part of the problem is the variability in wind direction over a 48 hr time frame (e.g. Figs. 2.iii and 3.iii). Another problem is selecting the correct starting date and time for back trajectory calculations. Figure 6 shows surface level back trajectories for Marathon for 4 different starting periods over 2 different sampling periods and suggests the difficulty involved in choosing an appropriate back trajectory when the end-use is source attribution. Although it is not possible to ascribe ambient levels of PCDD/PCDF to the pulp mills in these two small communities, it is appropriate to briefly put the results in context.

The Province of Ontario currently has an interim standard for PCDD/CDF calculated as:

$$(A) + (B/50) \leq 30 \text{ pg/m}^3$$

where A is the annual average dioxin concentration and B is the annual average furan concentration, both in pg/m^3 .

For data sets with a constant detection limit and fewer than 50% non-detects, means calculated by substituting the detection limit for non-detects are not significantly different from means calculated by using half the detection limit or by setting the detection limit equal to zero (Steer and Diamond, internal memorandum). For data sets in which the detection limit changes from sample to sample (such as PCDD/CDF) it is less clear which method to use. Given the concern surrounding PCDD/CDF it is probably better to be more conservative rather than less, and so, when calculating averages, the reported detection limit was used for any non-detect results.

	n	Mean Dioxin (A) (pg/m ³) (annual average)	Mean Furan (B) (pg/m ³) (annual average)	(A)+(B/50)
MARATHON	13	0.78 (0.43)	0.66 (0.03)	0.79 (0.44)
SMOOTH ROCK FALLS	11	0.22	0.16	0.22
WINDSOR	13	2.08	2.05	2.12
TORONTO	5	0.81	0.65	0.82
DORSET	11	2.00	0.59	2.01
The last column may be compared with the interim standard of 30 pg/m ³ .				

As may be seen from the table above, ambient air concentrations of PCDD/CDF for 1990 in Marathon, Smooth Rock Falls, Windsor, Toronto, and Dorset are well below the Provincial interim standard of 30 pg/m³. For Marathon, the numbers are calculated twice: initially including the first high sample; and (in brackets) excluding the first high sample.

In the table, Marathon compares well with Toronto which is somewhat surprising. Note, however, that few samples were collected in Toronto and that 4 of the 5 samples were collected in the fall/early winter (2 in Oct.; 1 in Nov.; and 1 in Dec.) and the calculated number is thus probably not representative of an annual average. It also should be noted that the Toronto site is on the Islands and *may* not be typical of the city.

Although this study has shown that ambient air concentrations of PCDD/PCDF are well below the interim standard in these two communities, the study failed to quantify any contribution to PCDD/PCDF by the pulp mills. For future studies of this type it is recommended that:

- i) sampling be conducted over a shorter time frame. With better detection limits now available, 24 hr sampling should be adequate, and in some cases it may be possible to sample over an even shorter time frame;
- ii) sampling be conducted only on those days when the plume can be located at ground level. This would ensure that the source of interest is being monitored;
- iii) simultaneous upwind/downwind sampling be conducted. By simultaneously sampling upwind and downwind, the contribution by the source of interest to local ambient air concentrations of targeted compounds could be better evaluated.

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TABLE II.

Ambient air concentrations in pg/m^3 followed, in brackets, by the number of isomers detected. Where the number of isomers reported is 0, the concentration is the detection limit.

63027 - MARATHON													
DATE	VOLUME	T4CDD	P5CDD	H6CDD	H7CDD	O8CDD	TOTALD	T4CDF	P5CDF	H6CDF	H7CDF	O8CDF	TOTALF
90/01/24	3290.9	0.300(7)	1.520(12)	1.140(6)	1.140(2)	0.790(1)	4.890	1.140(15)	0.550(13)	1.520(7)	0.950(4)	0.290(1)	4.450
90/02/21	3719.4	0.007(2)	0.020(5)	0.082(3)	0.140(2)	0.270(1)	0.519	0.110(12)	0.039(9)	0.181(1)	0.028(2)	0.030(1)	0.340
90/03/21	3606.0	0.017(4)	0.010(3)	0.020(3)	0.090(2)	0.350(1)	0.500	0.110(12)	0.042(4)	0.181(1)	0.028(2)	0.030(1)	0.340
90/04/18	3442.0	0.017(3)	0.004(1)	0.034(3)	0.047(2)	0.059(1)	0.261	0.080(10)	0.082(7)	0.059(4)	0.028(1)	0.044(1)	0.259
90/05/16	3421.0	0.027(5)	0.027(3)	0.034(3)	0.047(2)	0.059(1)	0.261	0.203(10)	0.082(7)	0.028(2)	0.025(1)	0.040(1)	0.378
90/05/16	3421.0	0.027(5)	0.027(3)	0.034(3)	0.047(2)	0.059(1)	0.261	0.044(6)	0.015(2)	0.010(0)	0.012(0)	0.026(0)	0.107
90/05/11	3873.0	0.042(1)	0.013(0)	0.015(0)	0.018(1)	0.102(1)	0.190	0.014(1)	0.013(0)	0.014(0)	0.017(0)	0.041(0)	0.223
90/08/11	3532.0	0.007(1)	0.028(0)	0.140(1)	0.110(0)	0.190(1)	0.475	0.006(0)	0.021(0)	0.008(0)	0.019(0)	0.008(0)	0.099
90/08/11	3532.0	0.007(1)	0.028(0)	0.140(1)	0.110(0)	0.190(1)	0.475	0.006(0)	0.021(0)	0.008(0)	0.019(0)	0.008(0)	0.099
90/09/08	4612.0	0.037(1)	0.007(0)	0.031(4)	0.017(1)	0.350(1)	0.437	0.140(11)	0.013(1)	0.012(1)	0.013(0)	0.140(1)	0.537
90/10/02	4302.0	0.008(1)	0.011(4)	0.034(6)	0.054(2)	0.220(1)	0.427	0.024(14)	0.024(9)	0.120(5)	0.088(4)	0.054(1)	0.536
90/10/31	3810.0	0.072(4)	0.042(4)	0.130(0)	0.256(2)	0.330(1)	0.441	0.007(0)	0.012(0)	0.012(1)	0.035(1)	0.025(1)	0.532
90/11/27	2063.0	0.010(0)	0.015(1)	0.058(4)	0.079(2)	0.170(1)	0.348	0.007(0)	0.012(0)	0.012(1)	0.035(1)	0.025(1)	0.532
91/01/06	2738.0	0.013(1)	0.028(2)	0.058(4)	0.079(2)	0.170(1)	0.348	0.430(14)	0.240(11)	0.140(5)	0.110(3)	0.019(1)	1.287
72095 - SMOOTH ROCK FALLS													
DATE	VOLUME	T4CDD	P5CDD	H6CDD	H7CDD	O8CDD	TOTALD	T4CDF	P5CDF	H6CDF	H7CDF	O8CDF	TOTALF
90/01/24	3475.0	0.010(1)	0.010(0)	0.010(0)	0.080(2)	0.060(0)	0.170	0.010(0)	0.010(0)	0.010(0)	0.020(0)	0.020(0)	0.240
90/02/20	3562.2	0.017(6)	0.016(2)	0.043(5)	0.088(2)	0.220(1)	0.384	0.150(15)	0.078(9)	0.025(4)	0.032(3)	0.023(1)	0.368
90/03/21	4170.0	0.020(2)	0.010(2)	0.010(2)	0.040(2)	0.150(1)	0.230	0.080(13)	0.020(5)	0.010(0)	0.007(0)	0.037(0)	0.162
90/04/17	3392.0	0.027(2)	0.003(0)	0.007(0)	0.029(2)	0.084(1)	0.130	0.020(3)	0.014(0)	0.010(0)	0.007(0)	0.037(0)	0.177
90/05/16	4792.0	0.036(3)	0.018(0)	0.006(0)	0.020(2)	0.057(1)	0.204	0.117(10)	0.028(2)	0.017(0)	0.019(0)	0.053(0)	0.239
90/06/13	3743.0	0.053(1)	0.011(0)	0.010(0)	0.020(2)	0.088(1)	0.204	0.040(1)	0.015(0)	0.009(0)	0.012(0)	0.015(0)	0.192
90/08/08	3810.0	0.022(1)	0.027(0)	0.013(0)	0.042(0)	0.160(0)	0.120	0.040(1)	0.025(0)	0.009(0)	0.012(0)	0.026(0)	0.102
90/09/04	4079.0	0.015(1)	0.025(0)	0.025(1)	0.026(0)	0.016(0)	0.109	0.013(0)	0.015(0)	0.014(0)	0.120(0)	0.026(0)	0.284
90/10/02	4362.0	0.004(1)	0.003(0)	0.013(2)	0.065(2)	0.320(1)	0.405	0.120(15)	0.110(2)	0.015(0)	0.094(0)	0.030(0)	0.369
90/10/31	3927.0	0.011(0)	0.010(0)	0.064(7)	0.099(2)	0.150(1)	0.334	0.034(3)	0.012(0)	0.046(6)	0.028(3)	0.022(1)	0.476

TABLE III. Summary statistics for ambient air concentrations of PCDD/CDF (pg/m³). # is number of samples collected and (ND) is number of non-detects.

MARATHON (pg/m ³)					
	AVG	STD	MAX	MIN	# (ND)
T4CDD	0.047	0.076	0.300	0.007	13(2)
P5CDD	0.135	0.400	1.520	0.004	13(5)
H6CDD	0.135	0.293	1.140	0.010	13(3)
H7CDD	0.167	0.289	1.140	0.010	13(2)
O8CDD	0.291	0.201	0.790	0.035	13(0)
D2378	0.010	0.000	0.011	0.010	3(3)
D12378	0.012	0.004	0.015	0.007	3(2)
D123478	0.009	0.002	0.012	0.006	3(2)
D123678	0.011	0.001	0.012	0.010	3(2)
D123789	0.014	0.004	0.019	0.010	3(1)
D1234678	0.080	0.049	0.150	0.044	3(0)
T4CDF	0.232	0.321	1.140	0.006	13(2)
P5CDF	0.108	0.150	0.550	0.012	13(3)
H6CDF	0.152	0.397	1.520	0.008	13(3)
H7CDF	0.108	0.245	0.950	0.012	13(4)
O8CDF	0.058	0.072	0.290	0.008	13(3)
F2378	0.062	0.042	0.110	0.007	3(1)
F23478	0.021	0.009	0.033	0.012	3(1)
F12378	0.016	0.005	0.024	0.012	3(1)
F123478	0.026	0.010	0.036	0.012	3(0)
F123678	0.013	0.002	0.016	0.010	3(1)
F234678	0.015	0.004	0.020	0.010	3(1)
F123789	0.010	0.003	0.014	0.007	3(3)
F1234678	0.036	0.012	0.047	0.019	3(0)
F1234789	0.008	0.000	0.009	0.008	3(2)

TABLE III. Cont'd.

SMOOTH ROCK FALLS (pg/m ³)					
	AVG	STD	MAX	MIN	# (ND)
T4CDD	0.029	0.026	0.100	0.004	11(1)
P5CDD	0.012	0.007	0.027	0.003	11(9)
H6CDD	0.020	0.017	0.064	0.006	11(6)
H7CDD	0.048	0.029	0.099	0.017	11(3)
O8CDD	0.110	0.089	0.320	0.016	11(3)
D2378			0.011		1(0)
D12378			0.010		1(1)
D123478			0.004		1(1)
D123678			0.004		1(1)
D123789			0.011		1(1)
D1234678			0.043		1(1)
T4CDF	0.056	0.049	0.150	0.003	11(3)
P5CDF	0.029	0.032	0.110	0.003	11(7)
H6CDF	0.016	0.011	0.046	0.003	11(7)
H7CDF	0.036	0.035	0.120	0.007	11(7)
O8CDF	0.025	0.011	0.053	0.007	11(7)
F2378			0.010		1(1)
F23478			0.012		1(1)
F12378			0.012		1(1)
F123478			0.012		1(0)
F123678			0.004		1(0)
F234678			0.007		1(0)
F123789			0.007		1(1)
F1234678			0.017		1(0)
F1234789			0.004		1(1)

TABLE III. Cont'd.

DORSET (pg/m ³)					
	AVG	STD	MAX	MIN	# (ND)
T4CDD	0.120	0.517	4.100	0.002	33(8)
P5CDD	0.056	0.240	1.900	0.002	33(19)
H6CDD	0.139	0.669	5.300	0.001	33(15)
H7CDD	0.186	0.555	3.000	0.001	32(1)
O8CDD	0.373	1.179	6.800	0.002	33(4)
D2378	0.010	0.007	0.030	0.001	16(15)
D12378	0.014	0.012	0.067	0.003	16(15)
D123478	0.012	0.015	0.076	0.001	16(15)
D123678	0.014	0.023	0.130	0.001	16(15)
D123789	0.017	0.043	0.250	0.001	16(12)
D1234678	0.076	0.302	1.700	0.001	15(0)
T4CDF	0.078	0.209	1.600	0.000	33(9)
P5CDF	0.045	0.126	0.800	0.002	33(14)
H6CDF	0.033	0.065	0.400	0.001	33(17)
H7CDF	0.059	0.180	1.300	0.001	33(13)
O8CDF	0.036	0.098	0.800	0.003	33(15)
F2378	0.011	0.006	0.024	0.003	16(12)
F23478	0.012	0.006	0.026	0.003	16(14)
F12378	0.011	0.006	0.023	0.003	16(14)
F123478	0.012	0.012	0.061	0.001	16(13)
F123678	0.011	0.010	0.053	0.001	16(14)
F234678	0.012	0.012	0.066	0.001	16(13)
F123789	0.199	1.042	6.000	0.001	16(16)
F1234678	0.013	0.018	0.100	0.001	16(9)
F1234789	0.008	0.004	0.019	0.001	16(13)

TABLE III. Cont'd.

TORONTO ISLAND (pg/m ³)					
	AVG	STD	MAX	MIN	# (ND)
T4CDD	0.118	0.310	1.900	0.001	22(2)
P5CDD	0.046	0.056	0.200	0.002	22(6)
H6CDD	0.094	0.120	0.500	0.002	22(1)
H7CDD	0.182	0.435	2.800	0.001	21(1)
O8CDD	0.252	0.273	1.200	0.009	22(0)
D2378	0.009	0.006	0.021	0.001	13(12)
D12378	0.013	0.010	0.039	0.002	13(10)
D123478	0.013	0.015	0.060	0.002	13(7)
D123678	0.014	0.015	0.066	0.002	13(7)
D123789	0.022	0.036	0.190	0.002	13(5)
D1234678	0.071	0.111	0.480	0.001	12(0)
T4CDF	0.205	0.406	2.400	0.001	22(2)
P5CDF	0.098	0.193	1.200	0.002	22(6)
H6CDF	0.101	0.144	0.740	0.002	22(2)
H7CDF	0.083	0.114	0.510	0.001	21(1)
O8CDF	0.065	0.078	0.380	0.003	22(2)
F2378	0.030	0.032	0.120	0.002	13(2)
F23478	0.016	0.012	0.051	0.002	13(4)
F12378	0.013	0.010	0.037	0.002	13(6)
F123478	0.027	0.027	0.110	0.003	13(3)
F123678	0.015	0.012	0.054	0.003	13(4)
F234678	0.017	0.014	0.059	0.003	13(5)
F123789	0.014	0.016	0.076	0.003	13(9)
F1234678	0.031	0.031	0.110	0.001	12(2)
F1234789	0.008	0.005	0.024	0.001	12(5)

TABLE III. Cont'd.

WINDSOR (pg/m ³)					
	AVG	STD	MAX	MIN	# (ND)
T4CDD	0.301	0.578	3.900	0.001	38(1)
P5CDD	0.237	0.867	7.200	0.002	38(2)
H6CDD	0.275	0.768	6.500	0.002	38(1)
H7CDD	0.443	0.824	5.200	0.003	37(1)
O8CDD	0.848	1.804	9.700	0.015	38(2)
D2378	0.035	0.083	0.400	0.001	15(12)
D12378	0.028	0.069	0.400	0.003	15(7)
D123478	0.026	0.069	0.400	0.002	15(3)
D123678	0.040	0.084	0.400	0.002	15(1)
D123789	0.038	0.071	0.400	0.002	14(0)
D1234678	0.134	0.165	0.650	0.004	15(0)
T4CDF	1.244	3.571	28.000	0.002	38(0)
P5CDF	0.521	1.313	7.500	0.001	38(1)
H6CDF	0.356	0.867	5.000	0.002	38(1)
H7CDF	0.308	0.729	5.600	0.002	37(3)
O8CDF	0.166	0.351	2.400	0.003	38(4)
F2378	0.187	0.466	2.300	0.004	15(0)
F23478	0.087	0.242	1.300	0.002	15(2)
F12378	0.591	2.997	17.000	0.002	15(2)
F123478	0.105	0.243	1.300	0.003	15(0)
F123678	0.046	0.082	0.400	0.003	15(1)
F234678	0.064	0.143	0.760	0.003	15(2)
F123789	0.026	0.046	0.200	0.003	15(8)
F1234678	0.116	0.206	1.100	0.002	15(0)
F1234789	0.028	0.050	0.210	0.002	14(3)

TABLE IV. International toxic equivalents shown for Marathon and Smooth Rock Falls. Summary statistics are also provided for comparison with Dorset, Toronto, and Windsor.

MARATHON - 63027			SMOOTH ROCK FALLS - 72095		
Sample Date	Total TEQ (pg/m ³)		Sample Date	Total TEQ (pg/m ³)	
24-Jan-90	0.3		24-Jan-90	0.003	
21-Feb-90	0.01		20-Feb-90	0.01	
21-Mar-90	0.01		21-Mar-90	0.005	
18-Apr-90	0.01		17-Apr-90	0.003	
16-May-90	0.02		16-May-90	0.005	
13-Jun-90	0.007		13-Jun-90	0.01	
11-Jul-90	0.006		11-Jul-90	0.006	
11-Aug-90	0.009		08-Aug-90	0.007	
08-Sep-90	0.01		04-Sep-90	0.01	
02-Oct-90	0.01		02-Oct-90	0.002	
31-Oct-90	0.07		31-Oct-90	0.007	
27-Nov-90	0.004		Missing		
06-Jan-91	0.05		Missing		
	Marathon	S.R. Falls	Dorset	Toronto	Windsor
Mean	0.04	0.007	0.02	0.04	0.2
Max	0.3	0.01	0.2	0.2	2
Min	0.004	0.002	0.003	0.008	0.01

For Figures 2.i through 3.xi wind speeds are in km/hr.

For Figures 3.i through 3.xi wind speeds are the average of the number of hours the wind was from that direction (the number at the end of the vector).

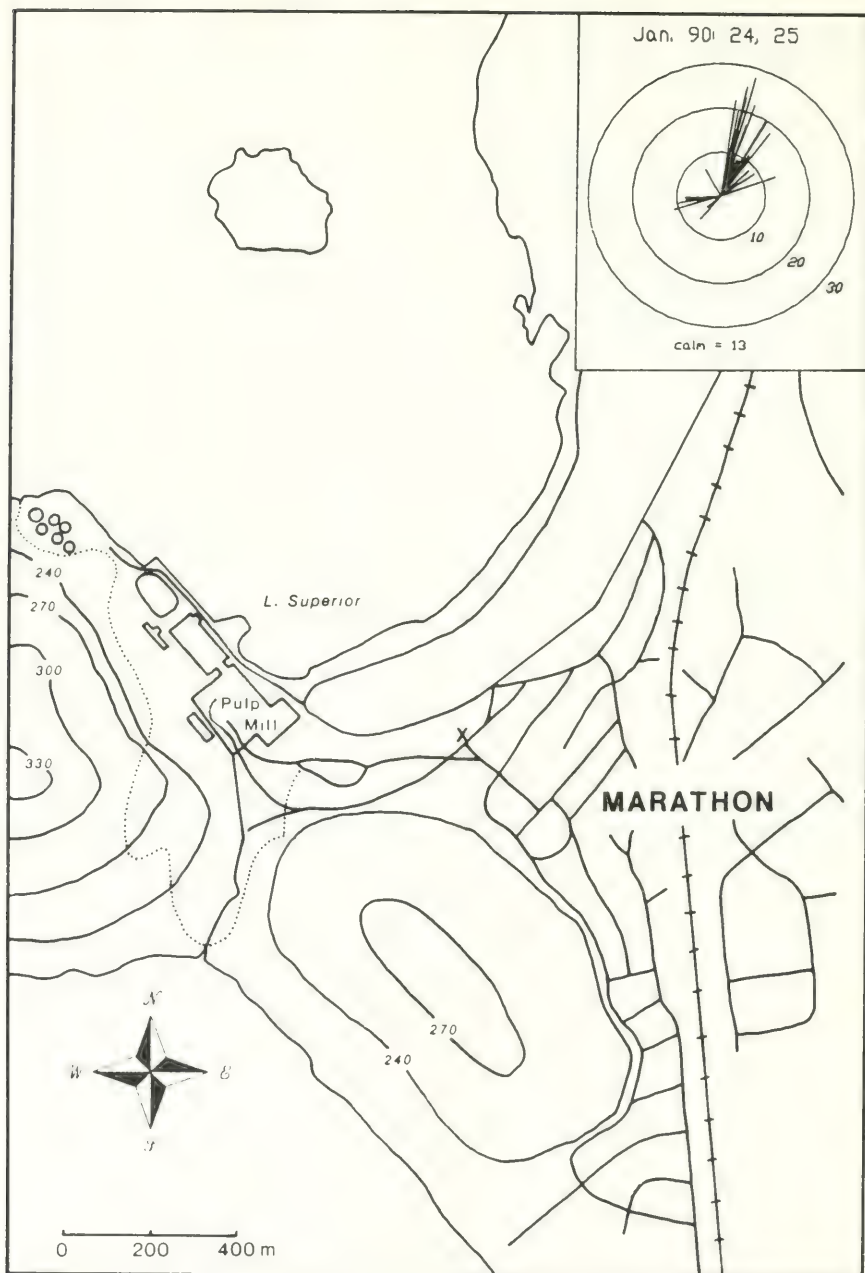


Figure 2.i. Marathon wind speed and direction, January 24 & 25, 1990.

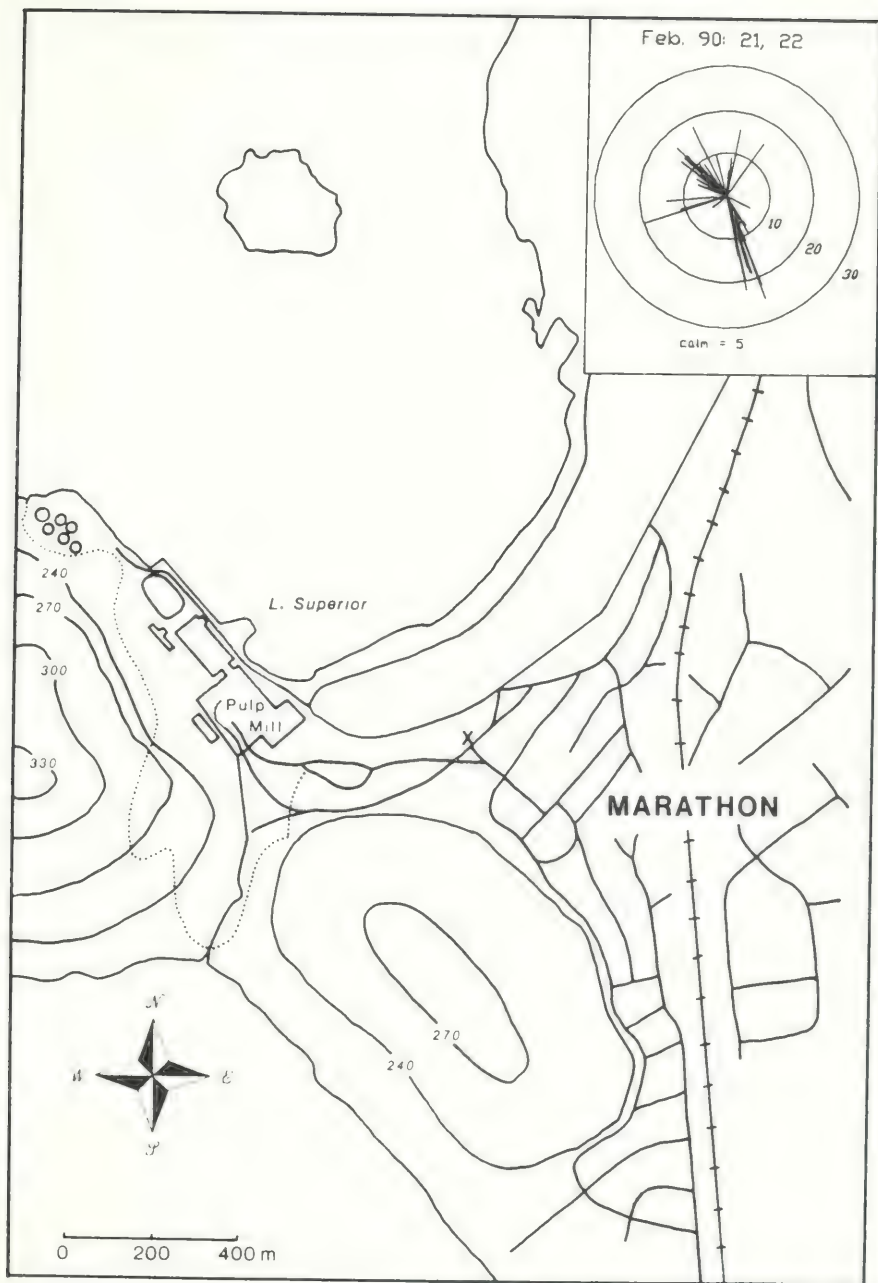


Figure 2.ii. Marathon wind speed and direction, February 21 & 22, 1990.

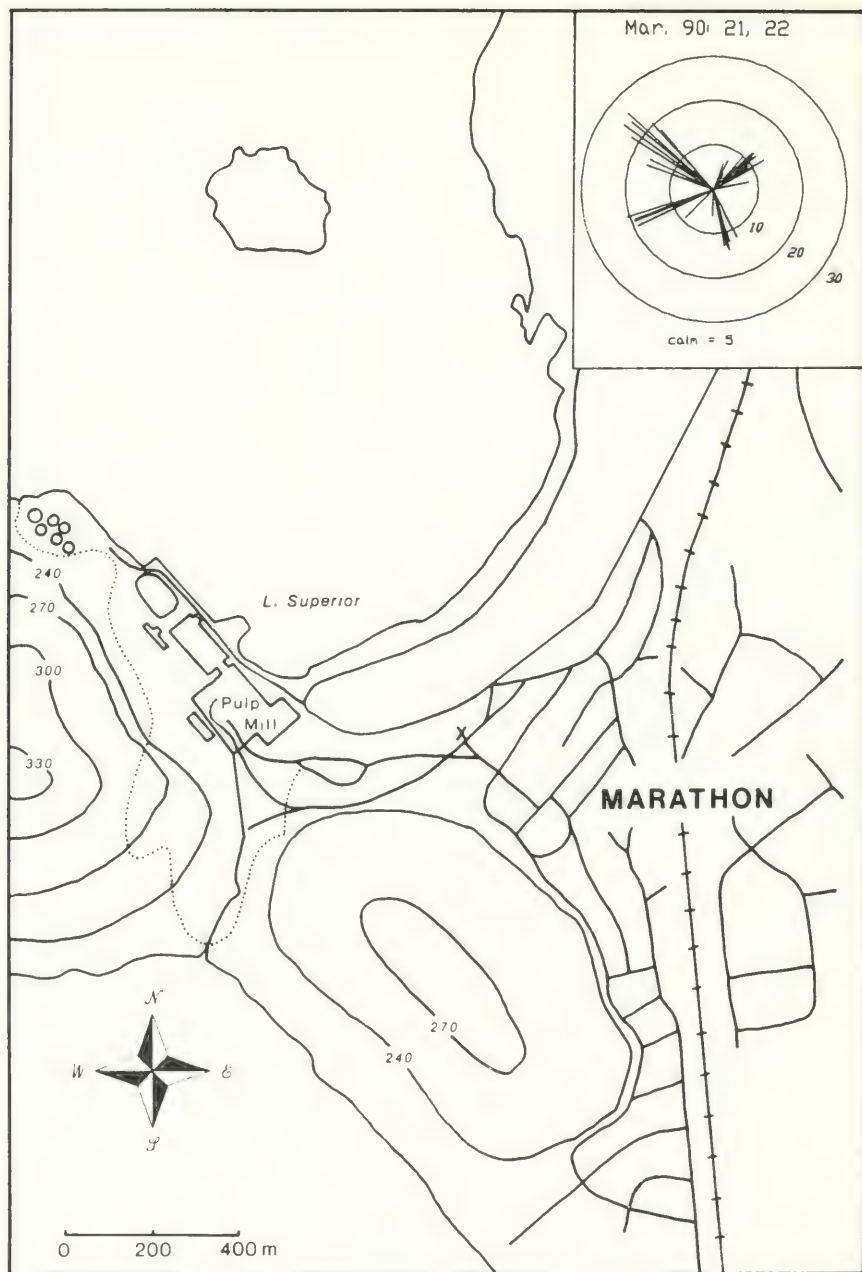


Figure 2.iii. Marathon wind speed and direction, March 21 & 22, 1990.

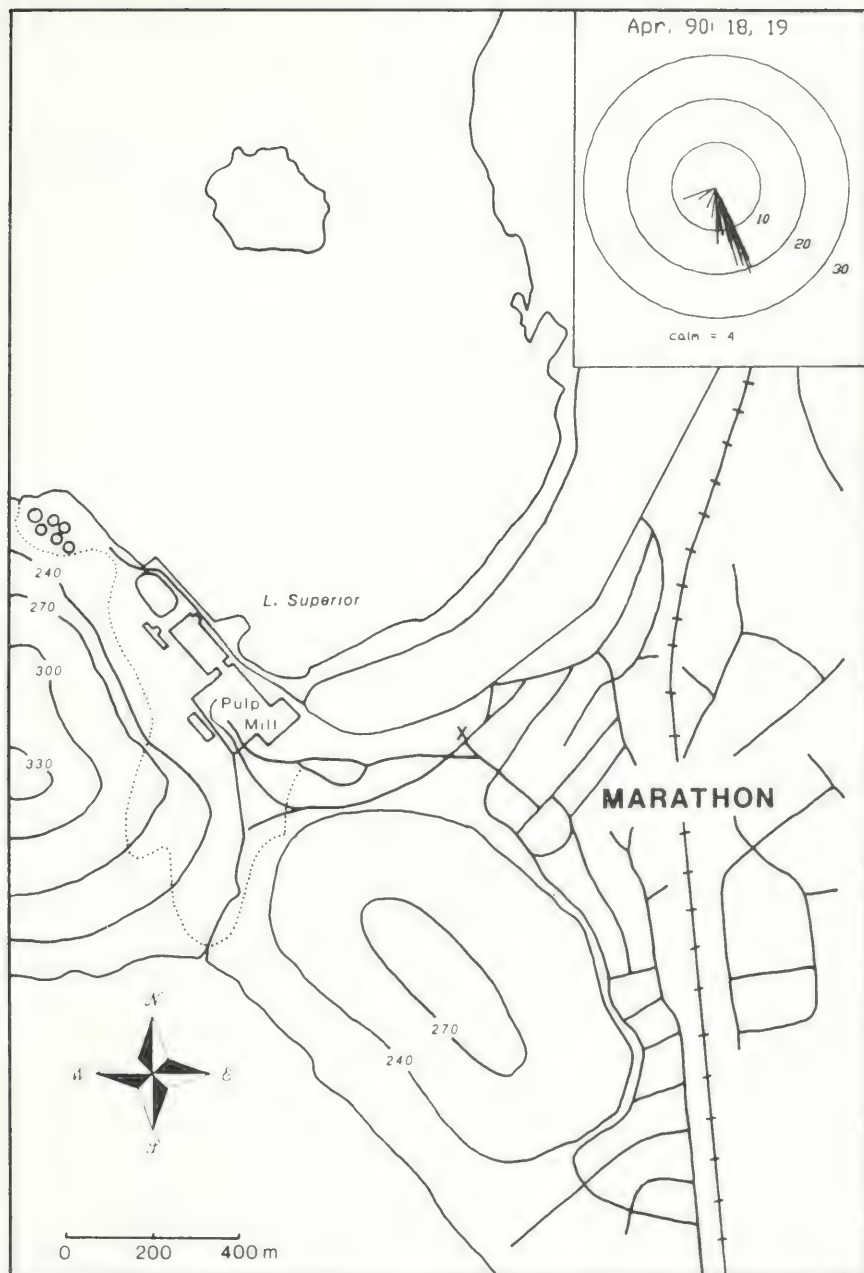


Figure 2.iv. Marathon wind speed and direction, April 18 & 19, 1990.

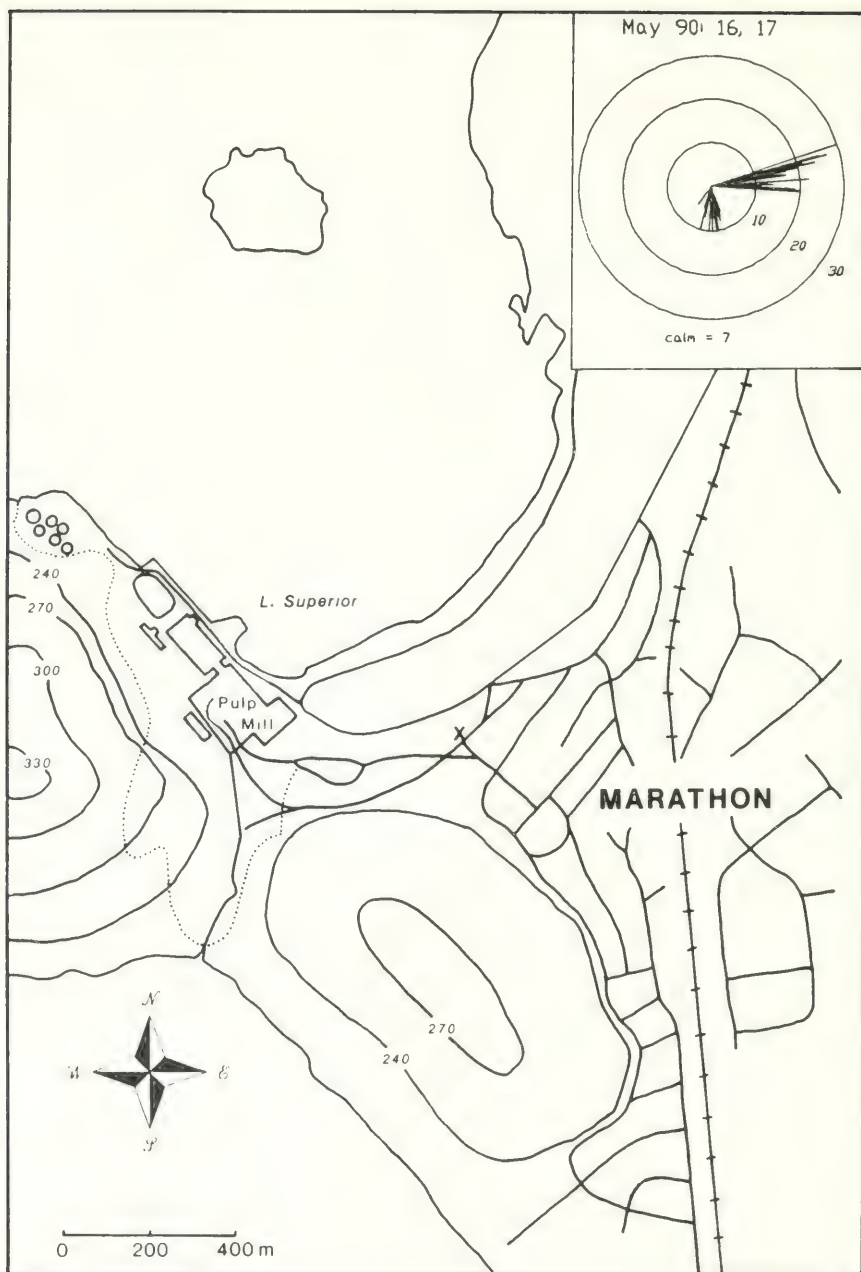


Figure 2.v. Marathon wind speed and direction, May 16 & 17, 1990.

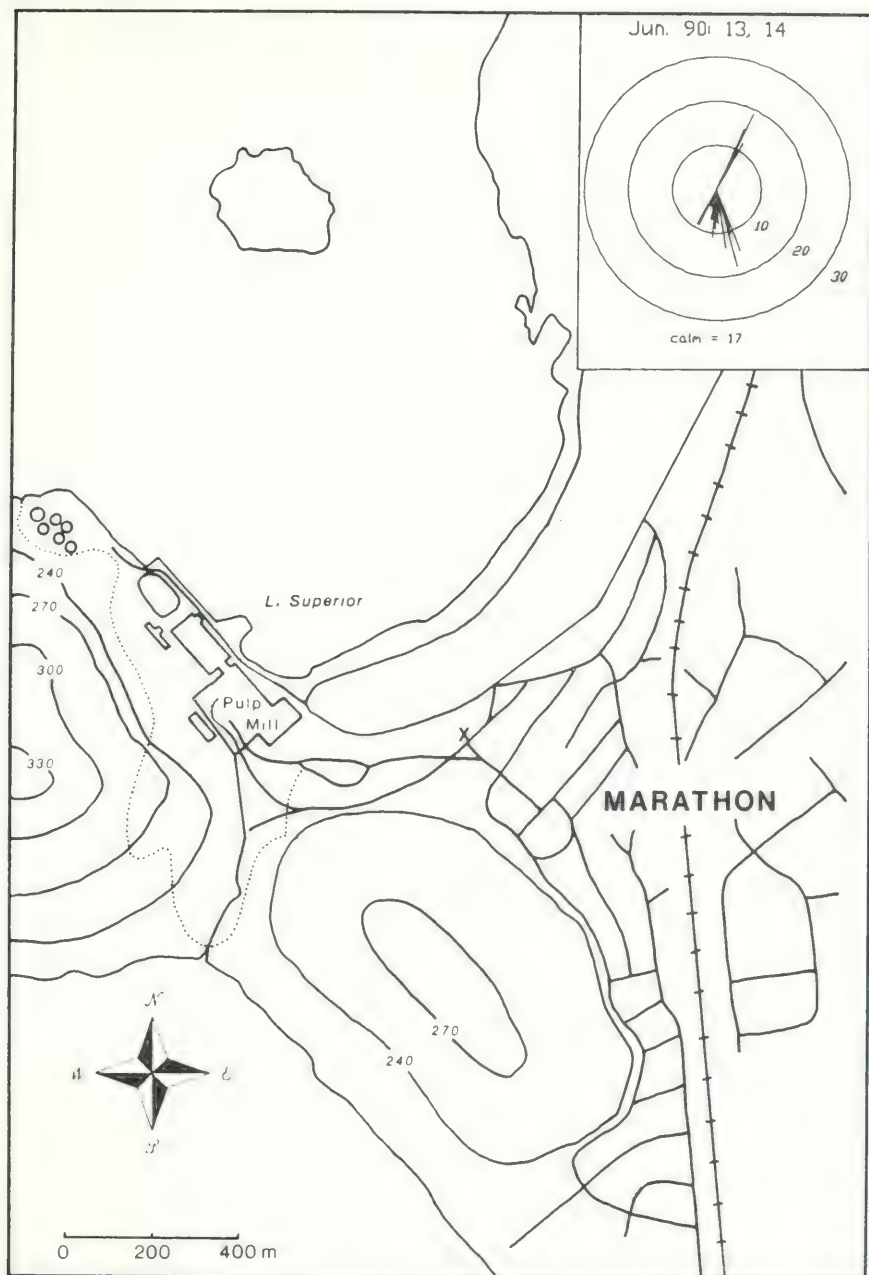


Figure 2.vi. Marathon wind speed and direction, June 13 & 14, 1990.

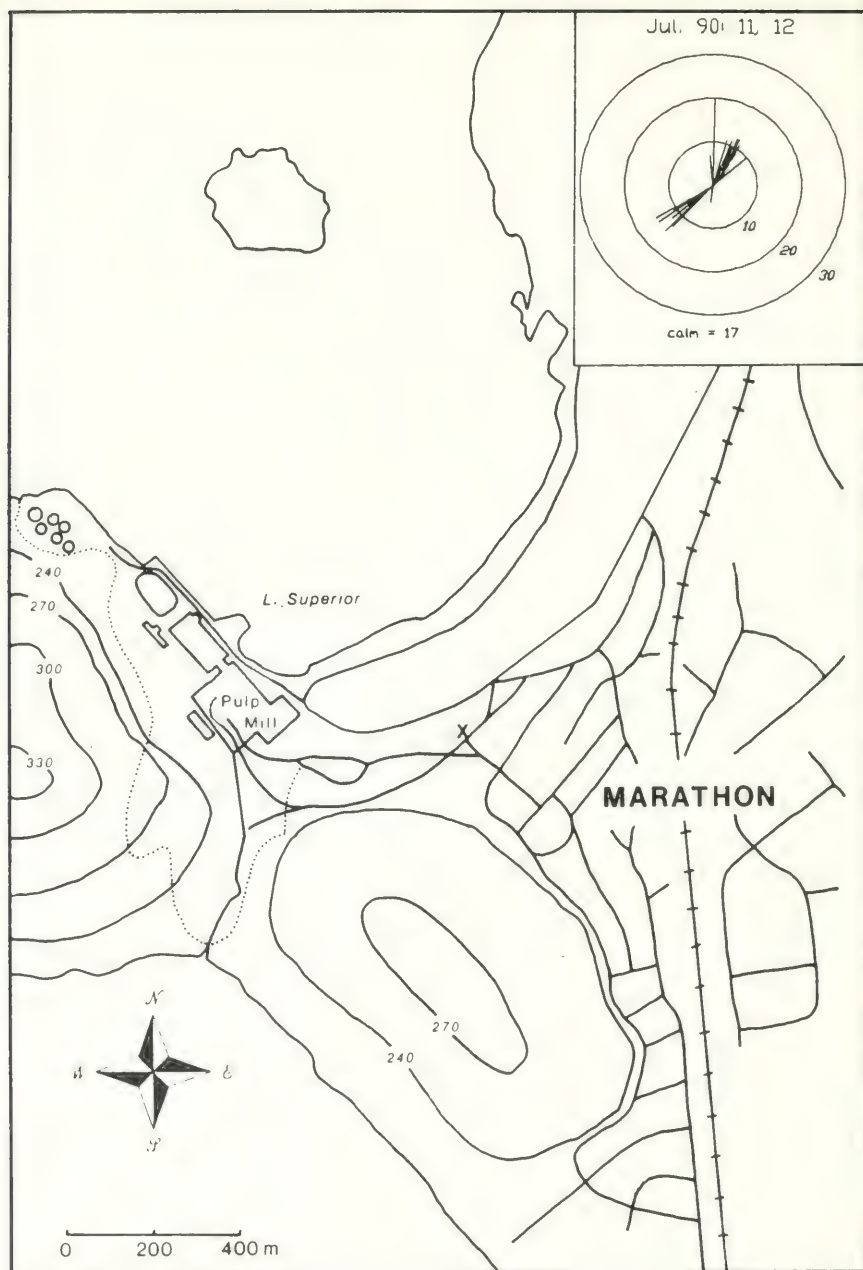


Figure 2.vii. Marathon wind speed and direction, July 11 & 12, 1990.

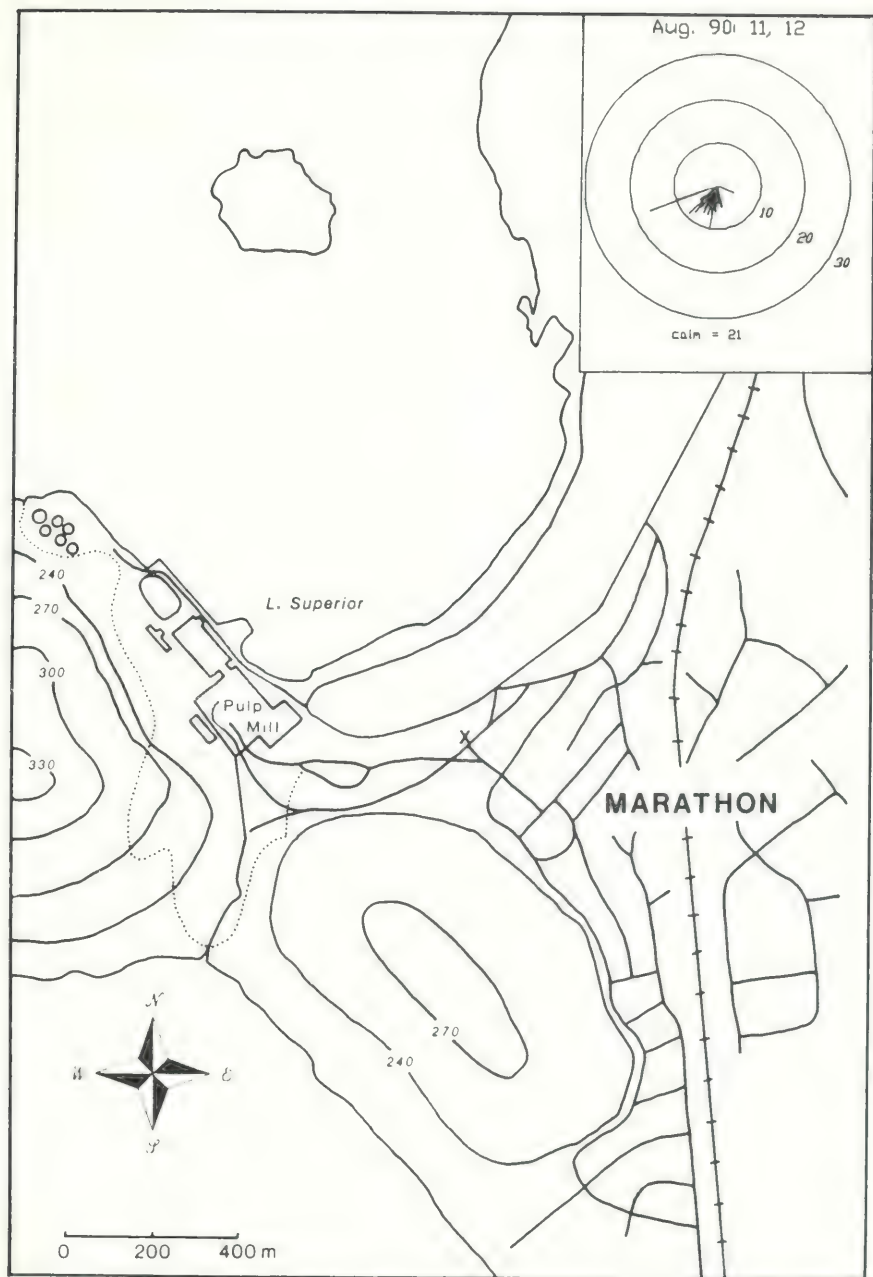


Figure 2.viii. Marathon wind speed and direction, August 11 & 12, 1990.

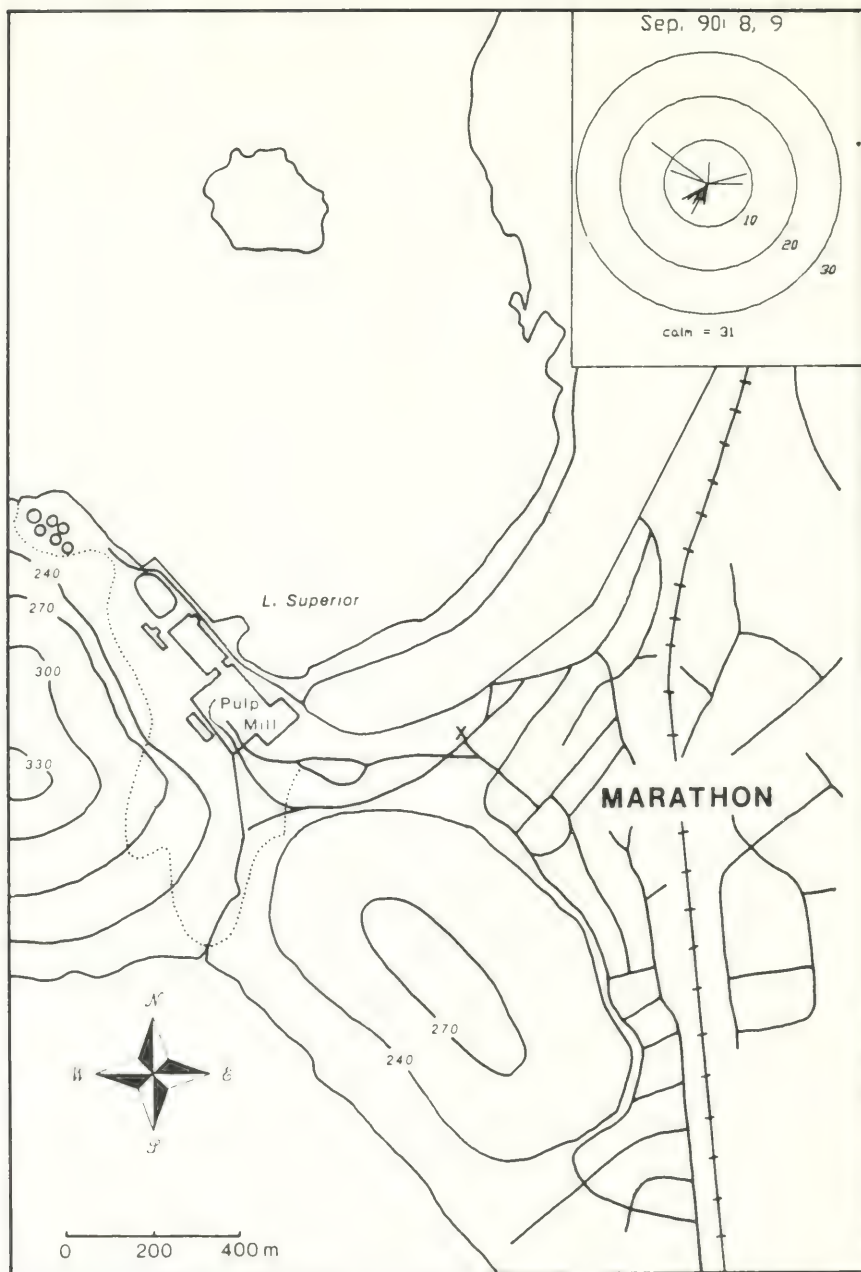


Figure 2.ix. Marathon wind speed and direction, September 8 & 9, 1990.

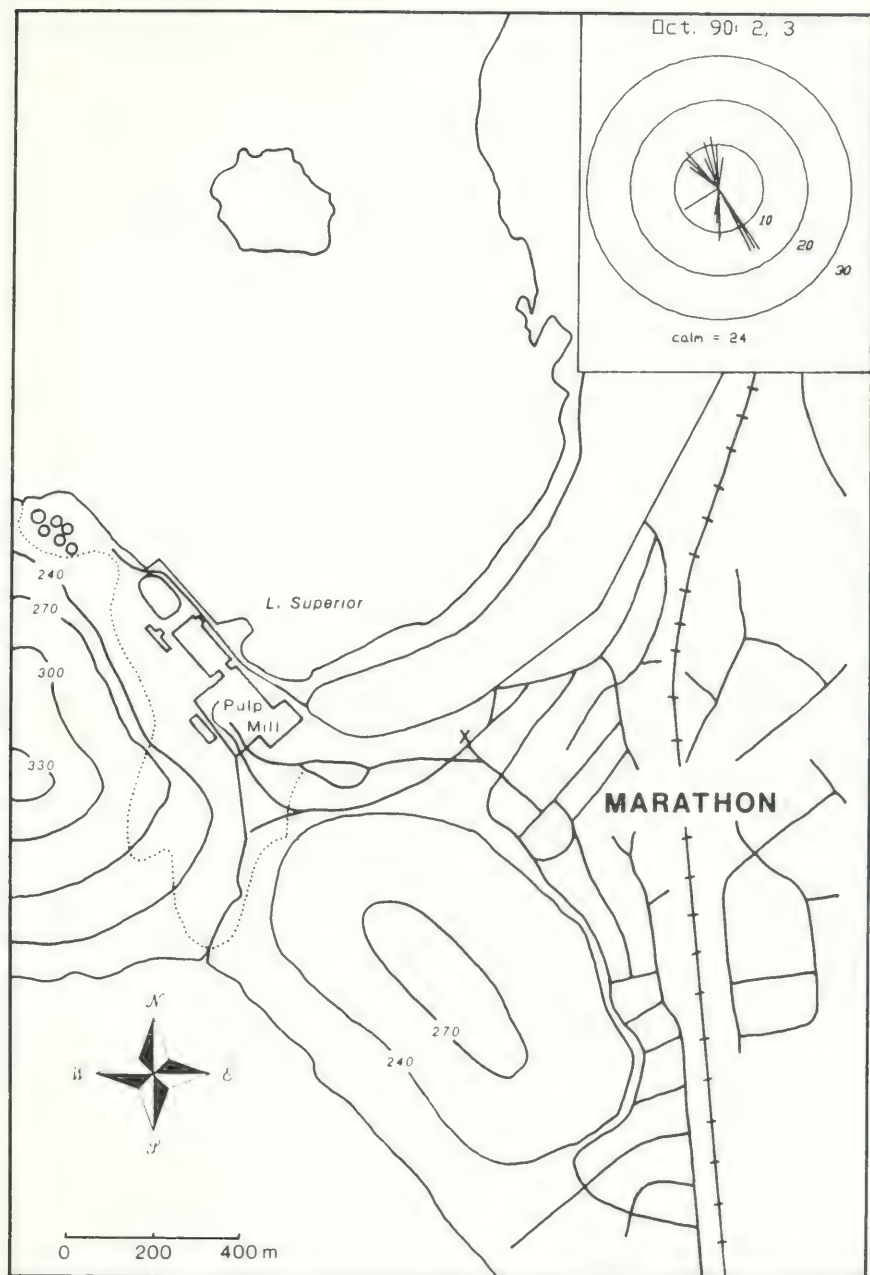


Figure 2.x. Marathon wind speed and direction, October 2 & 3, 1990.

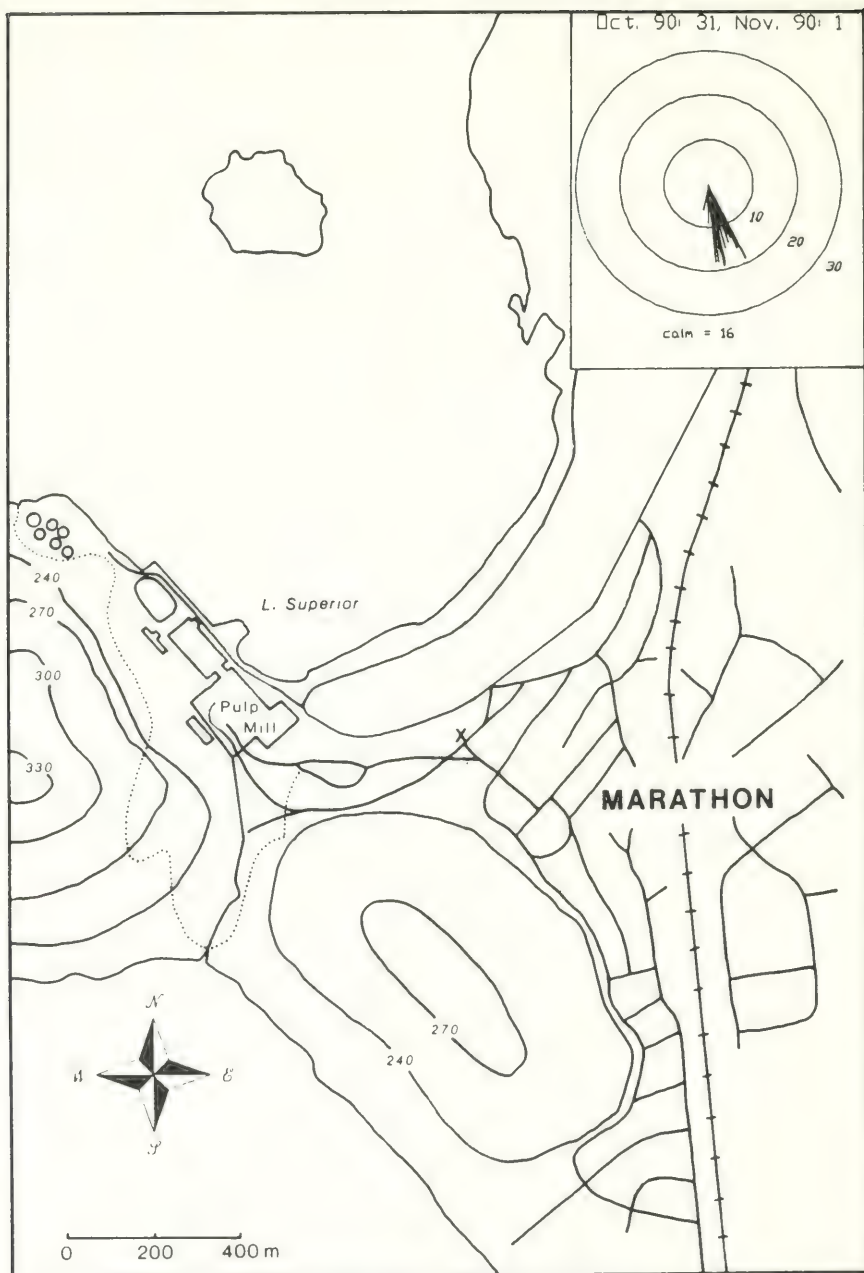


Figure 2.xi. Marathon wind speed and direction, October 31 & November 1, 1990.

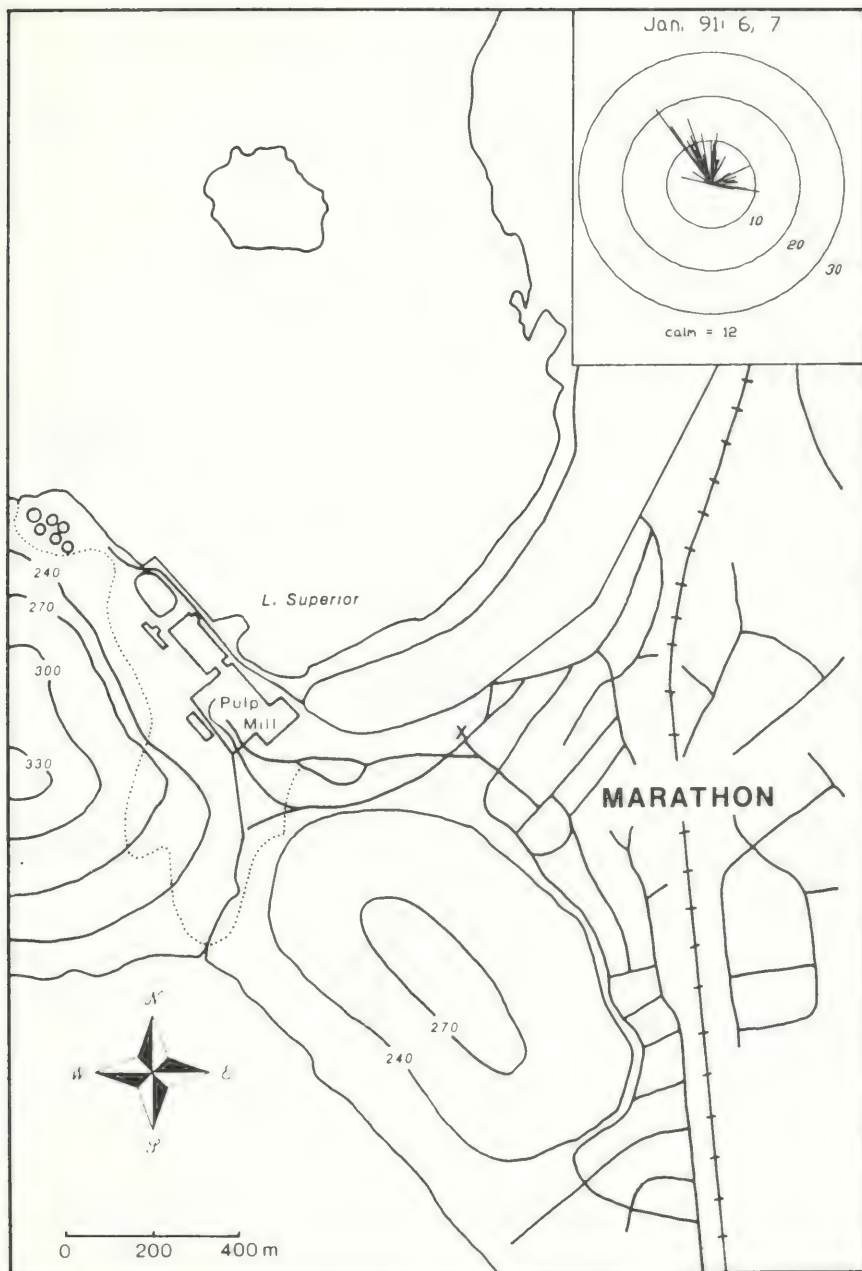


Figure 2.xii. Marathon wind speed and direction, January 6 & 7, 1991.

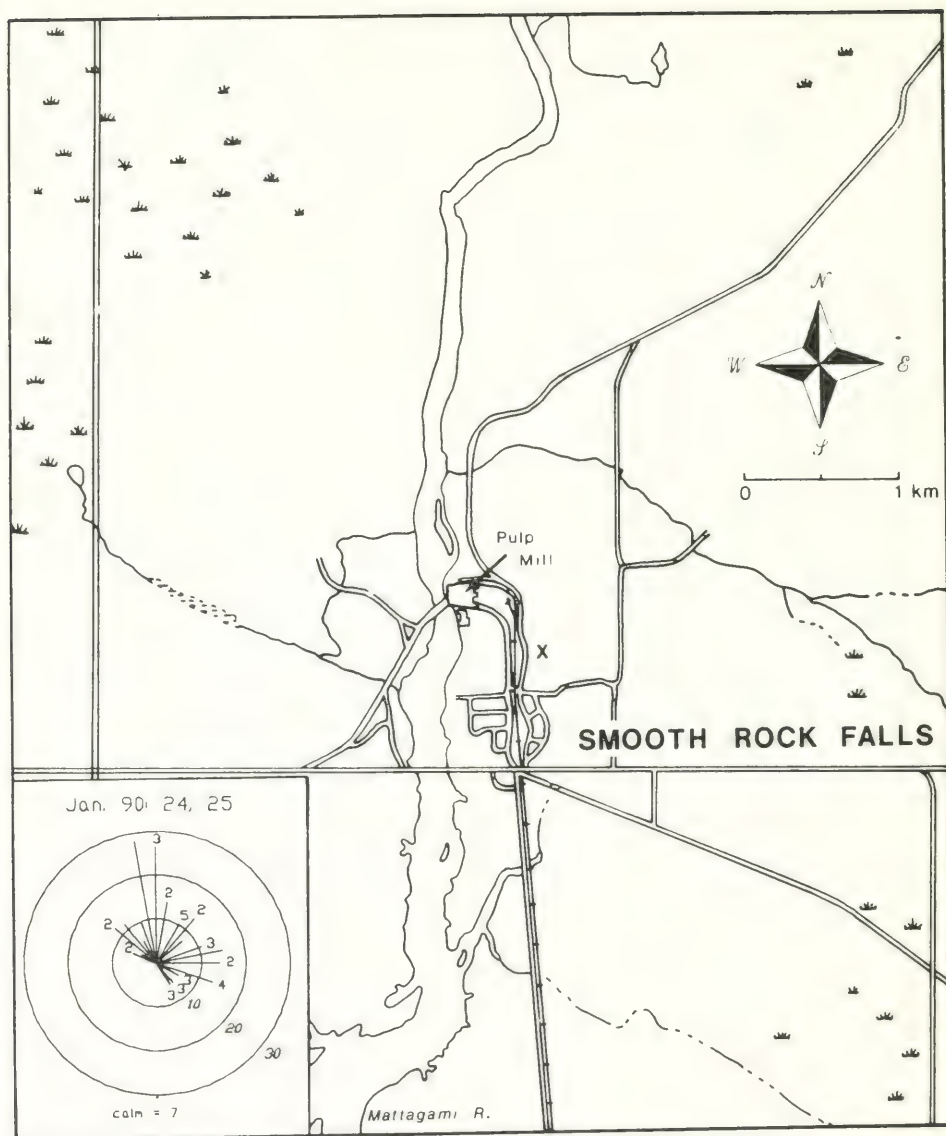


Figure 3.i. Smooth Rock Falls wind speed and direction, January 24 & 25, 1990.

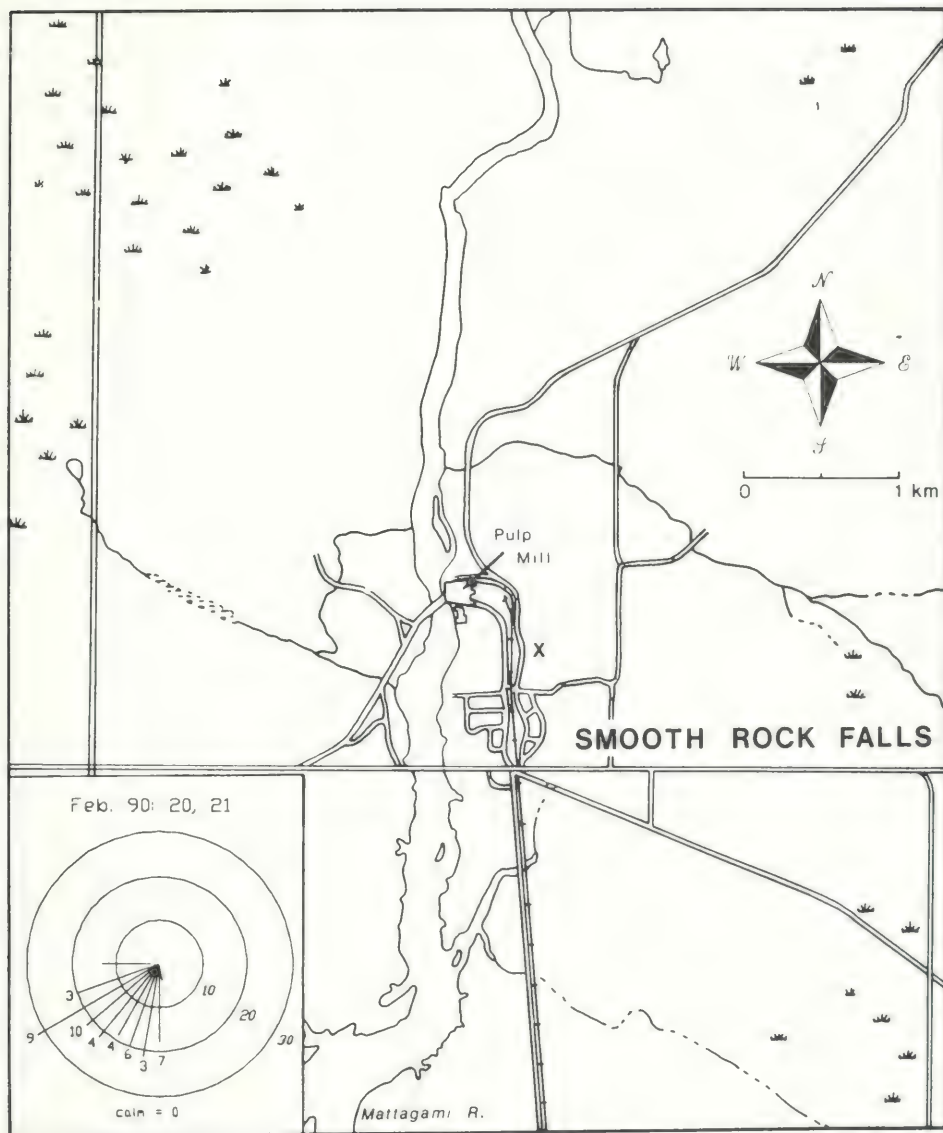


Figure 3.ii. Smooth Rock Falls wind speed and direction, February 20 & 21, 1990.

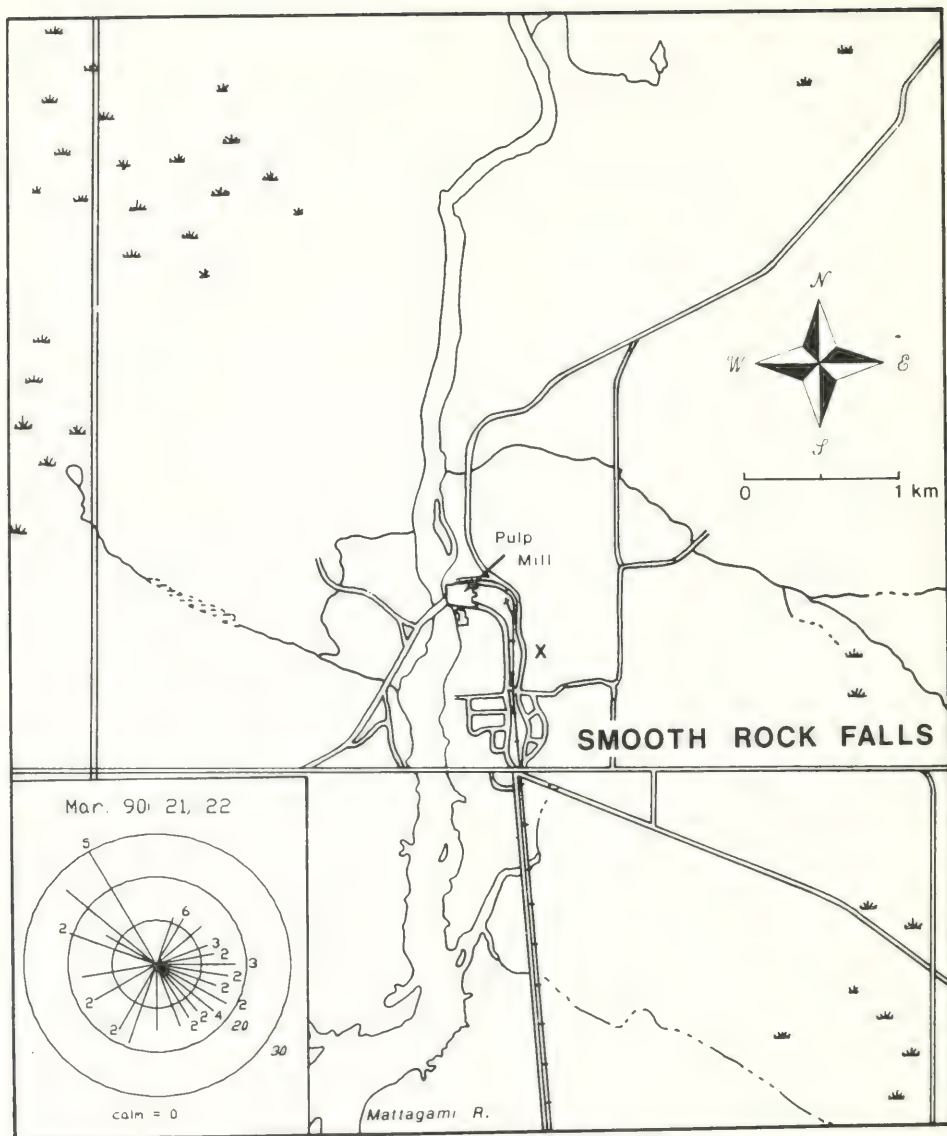


Figure 3.iii. Smooth Rock Falls wind speed and direction, March 21 & 22, 1990.

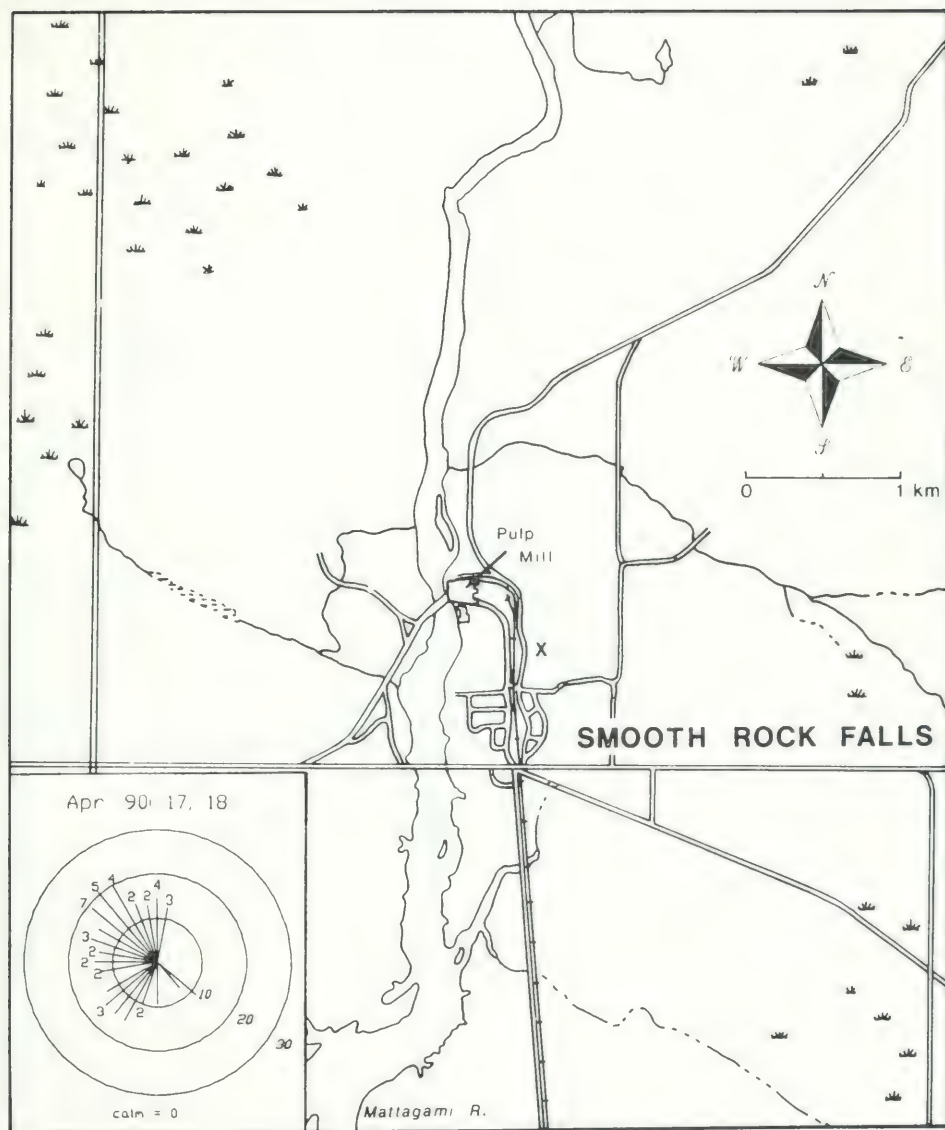


Figure 3.iv. Smooth Rock Falls wind speed and direction, April 17 & 18, 1990.

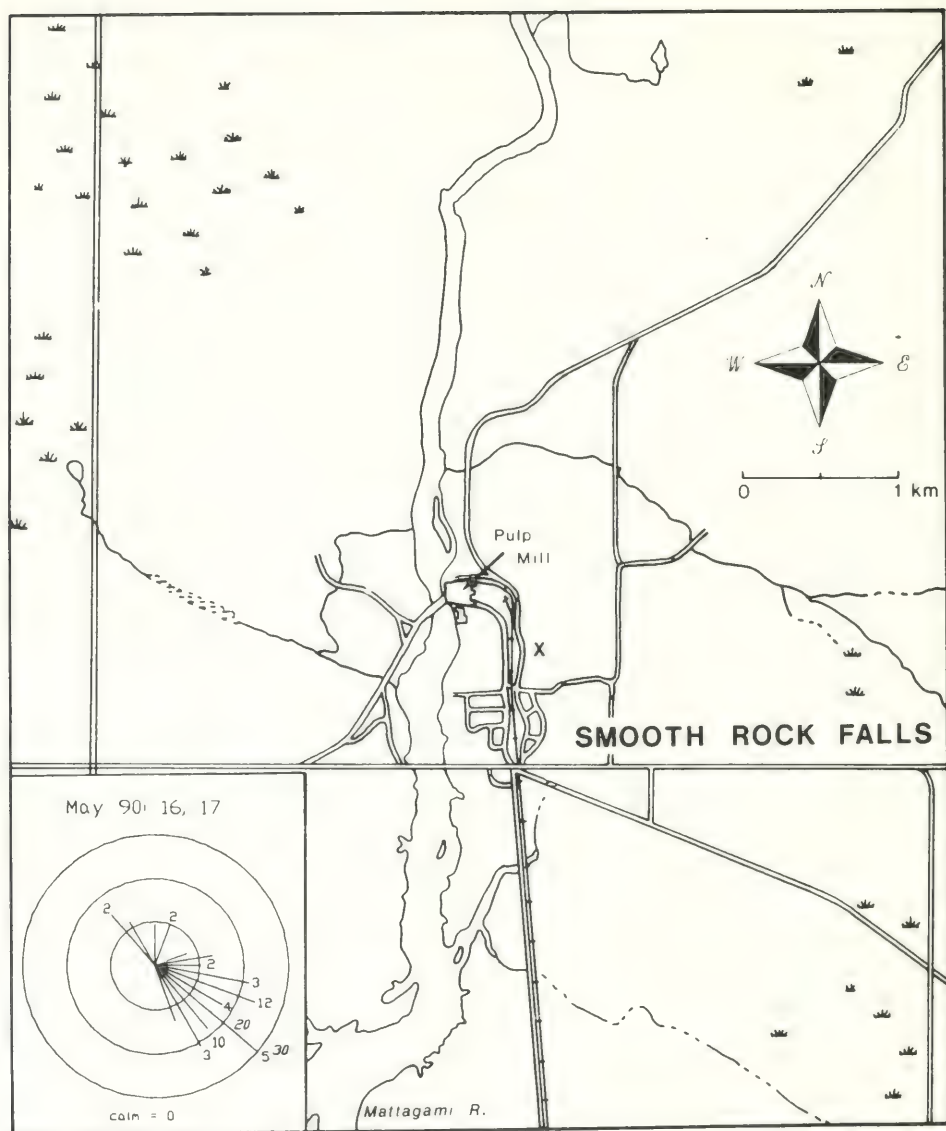


Figure 3.v. Smooth Rock Falls wind speed and direction, May 16 & 17, 1990.

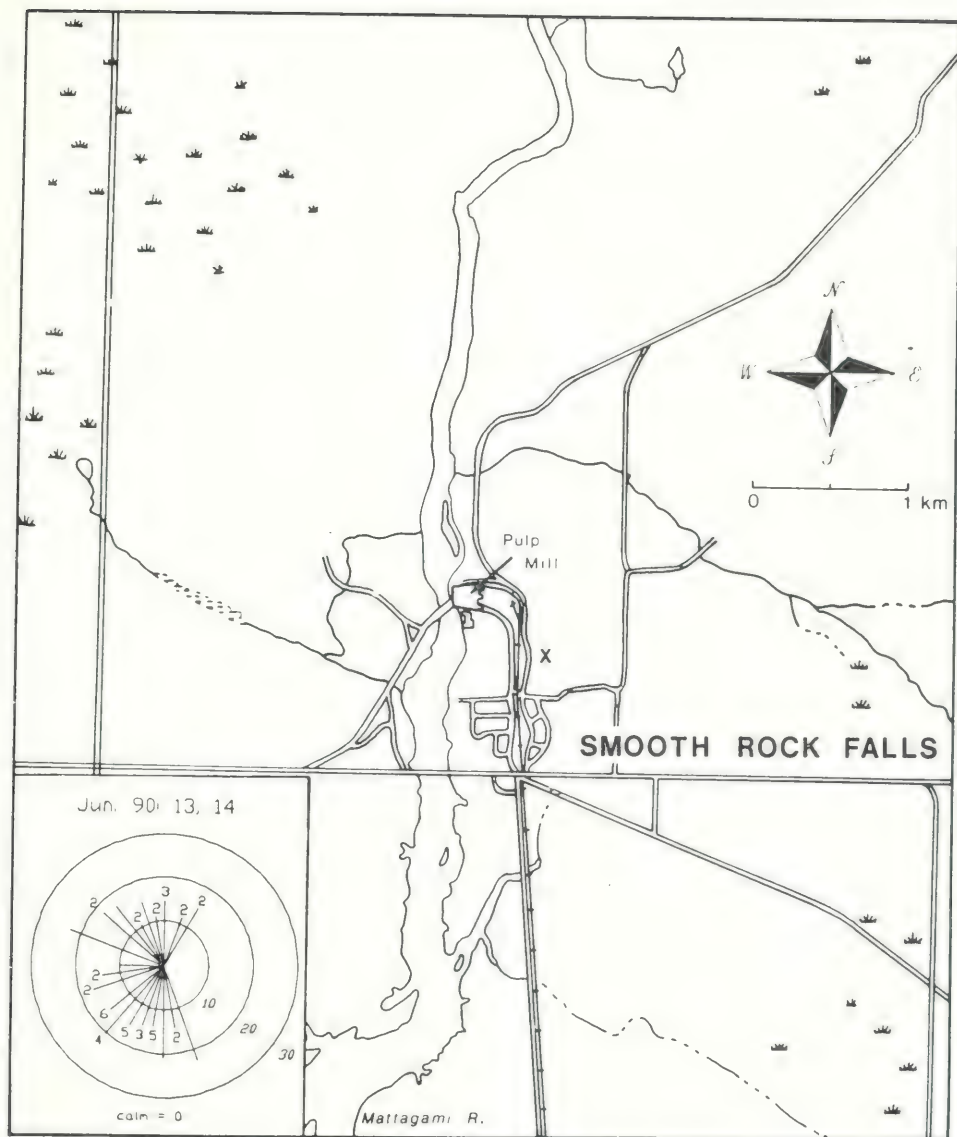


Figure 3.vi. Smooth Rock Falls wind speed and direction, June 13 & 14, 1990.

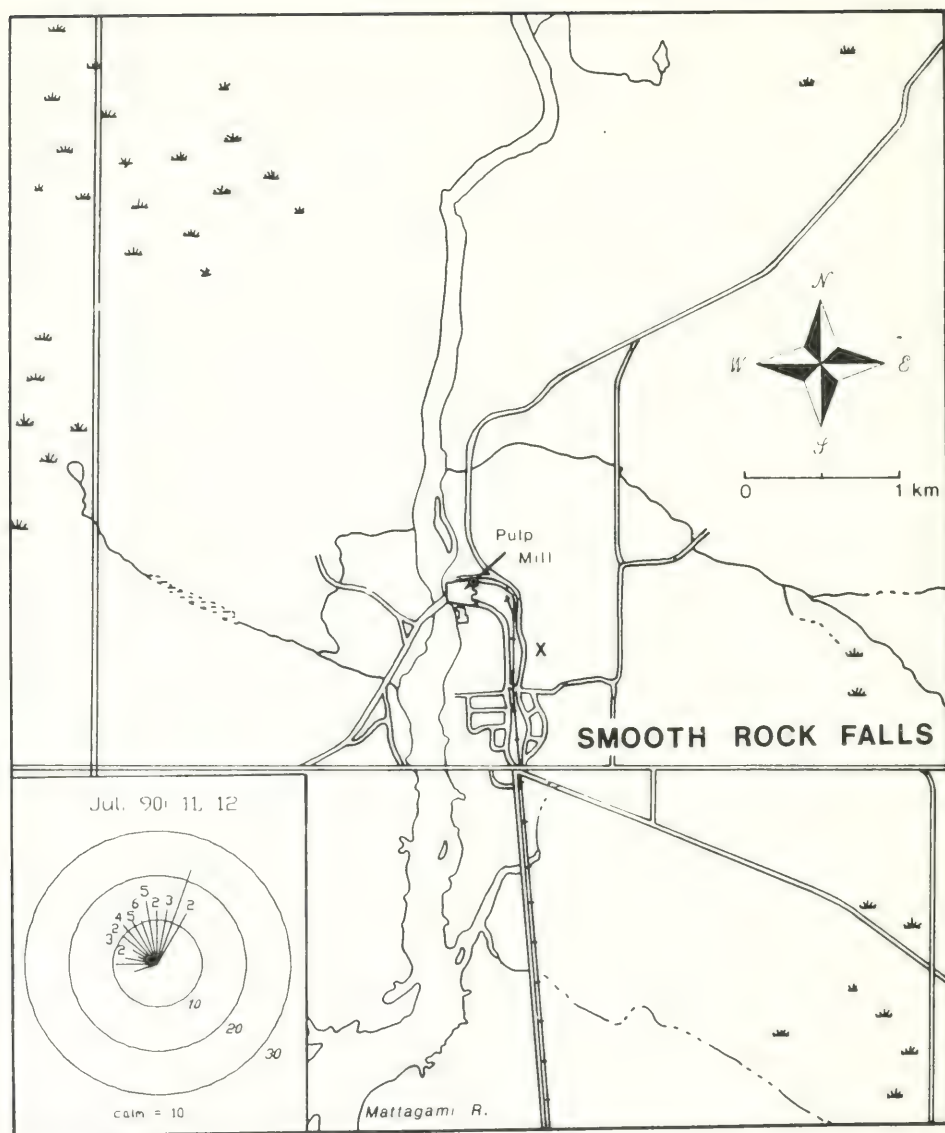


Figure 3.vii. Smooth Rock Falls wind speed and direction, July 11 & 12, 1990.

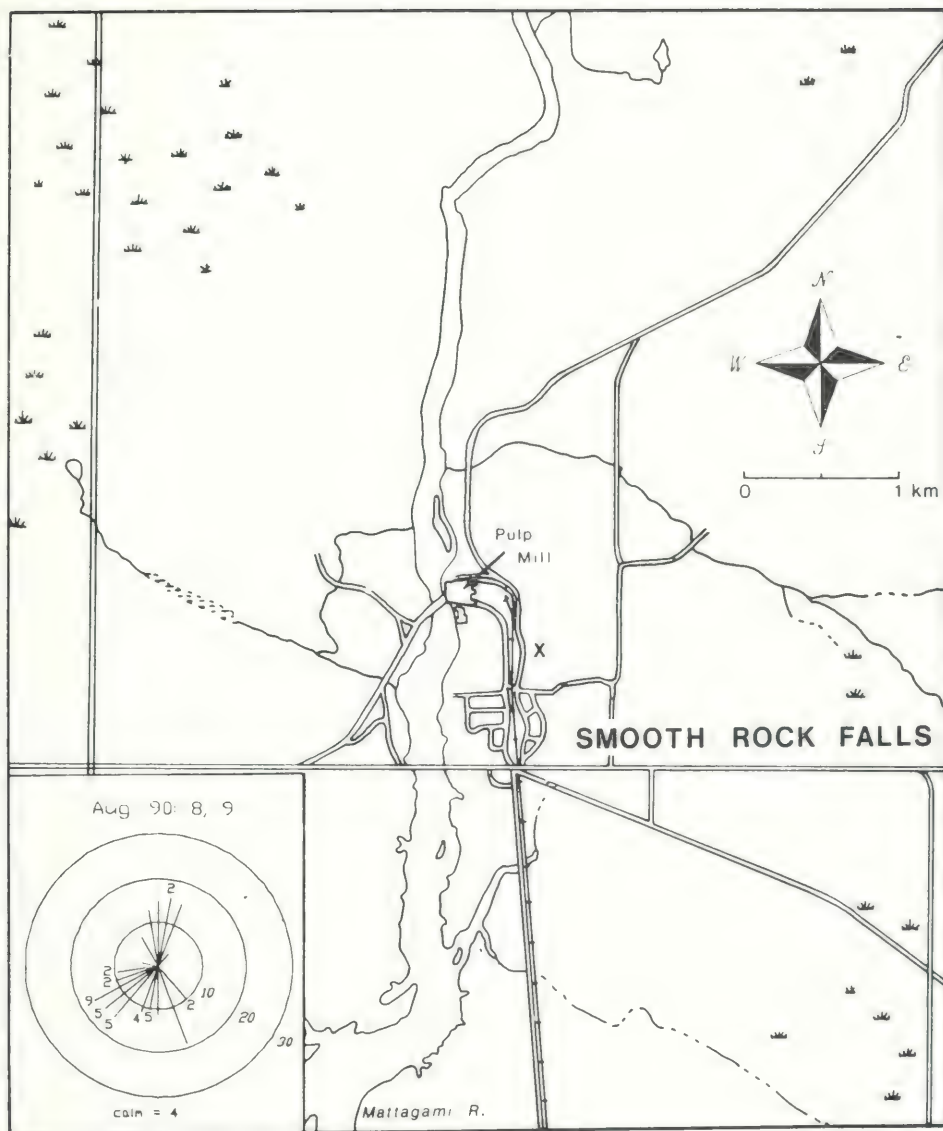


Figure 3.viii. Smooth Rock Falls wind speed and direction, August 8 & 9, 1990.

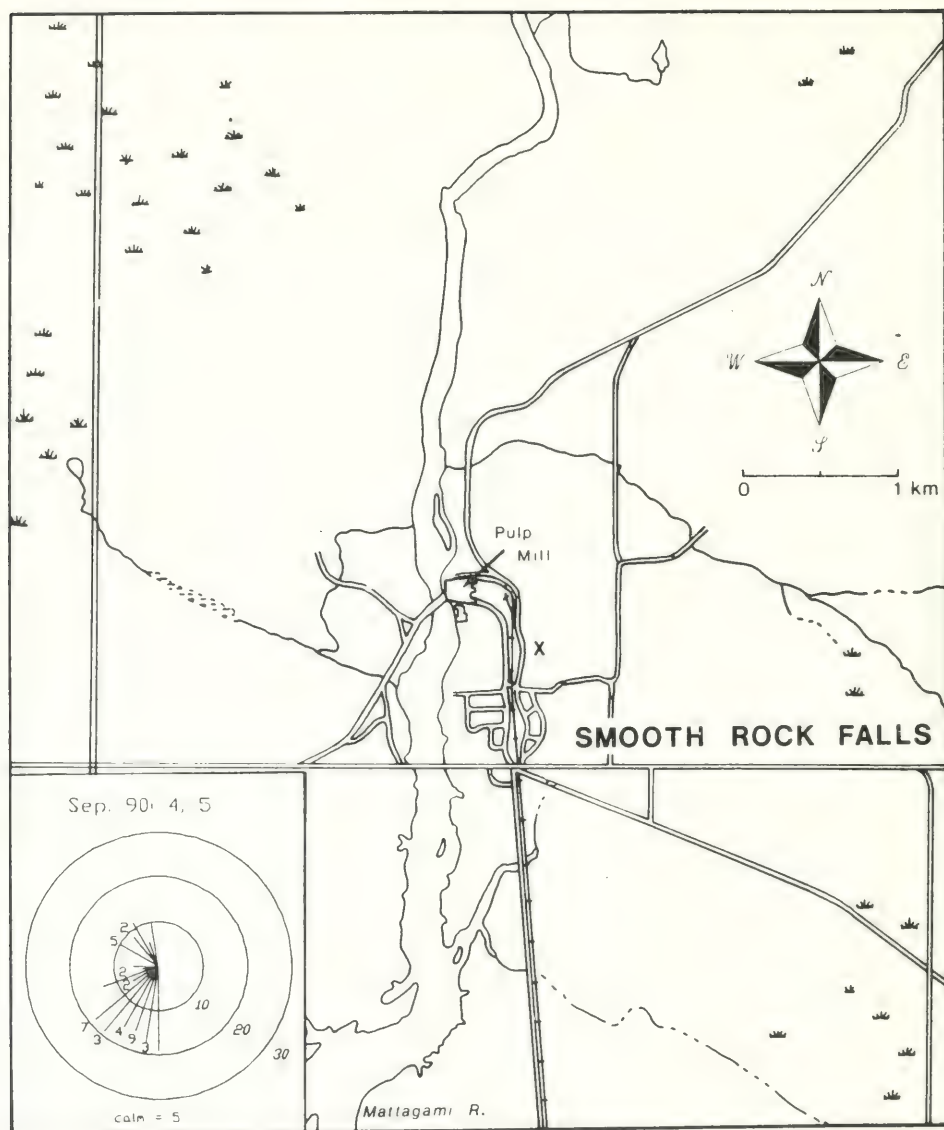


Figure 3.ix. Smooth Rock Falls wind speed and direction, September 4 & 5, 1990.

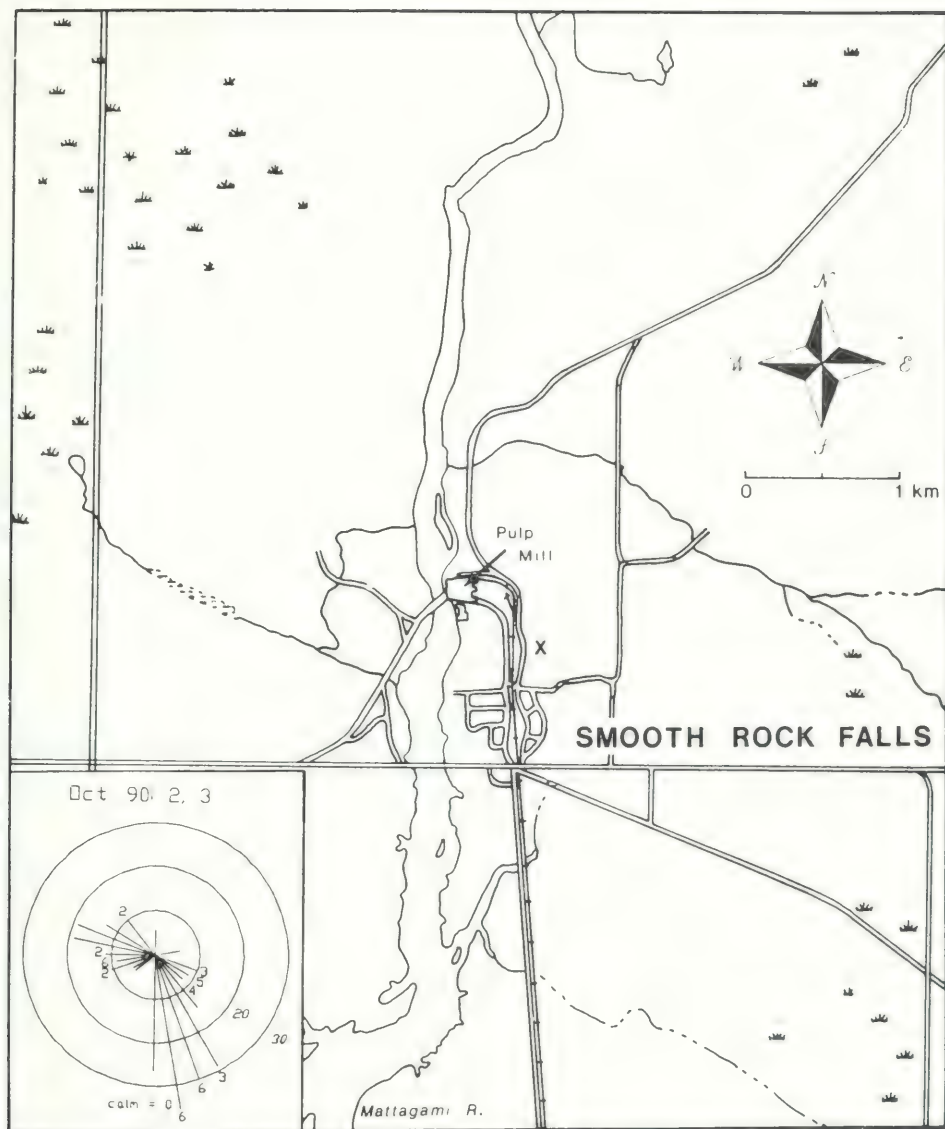


Figure 3.x. Smooth Rock Falls wind speed and direction, October 2 & 3, 1990.

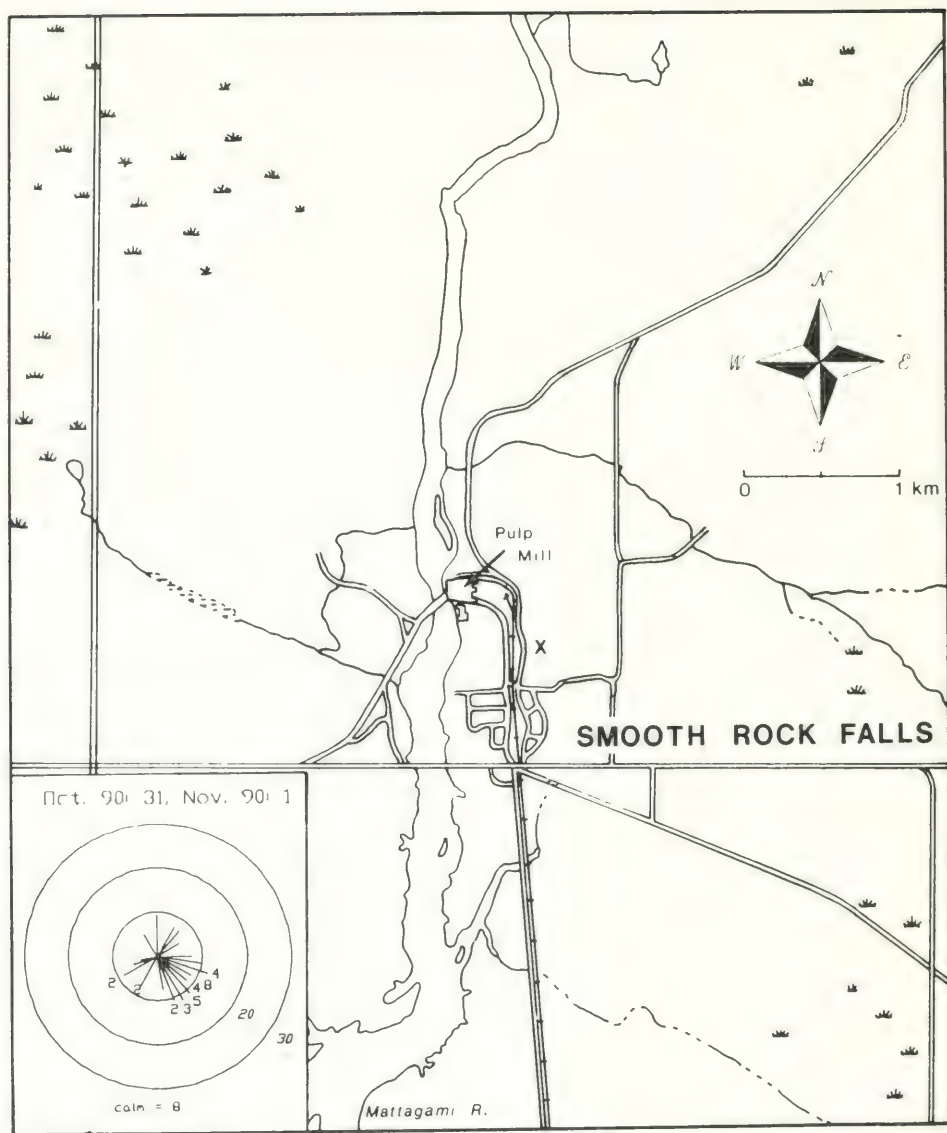


Figure 3.xi. Smooth Rock Falls wind speed and direction, October 31 & November 1, 1990.

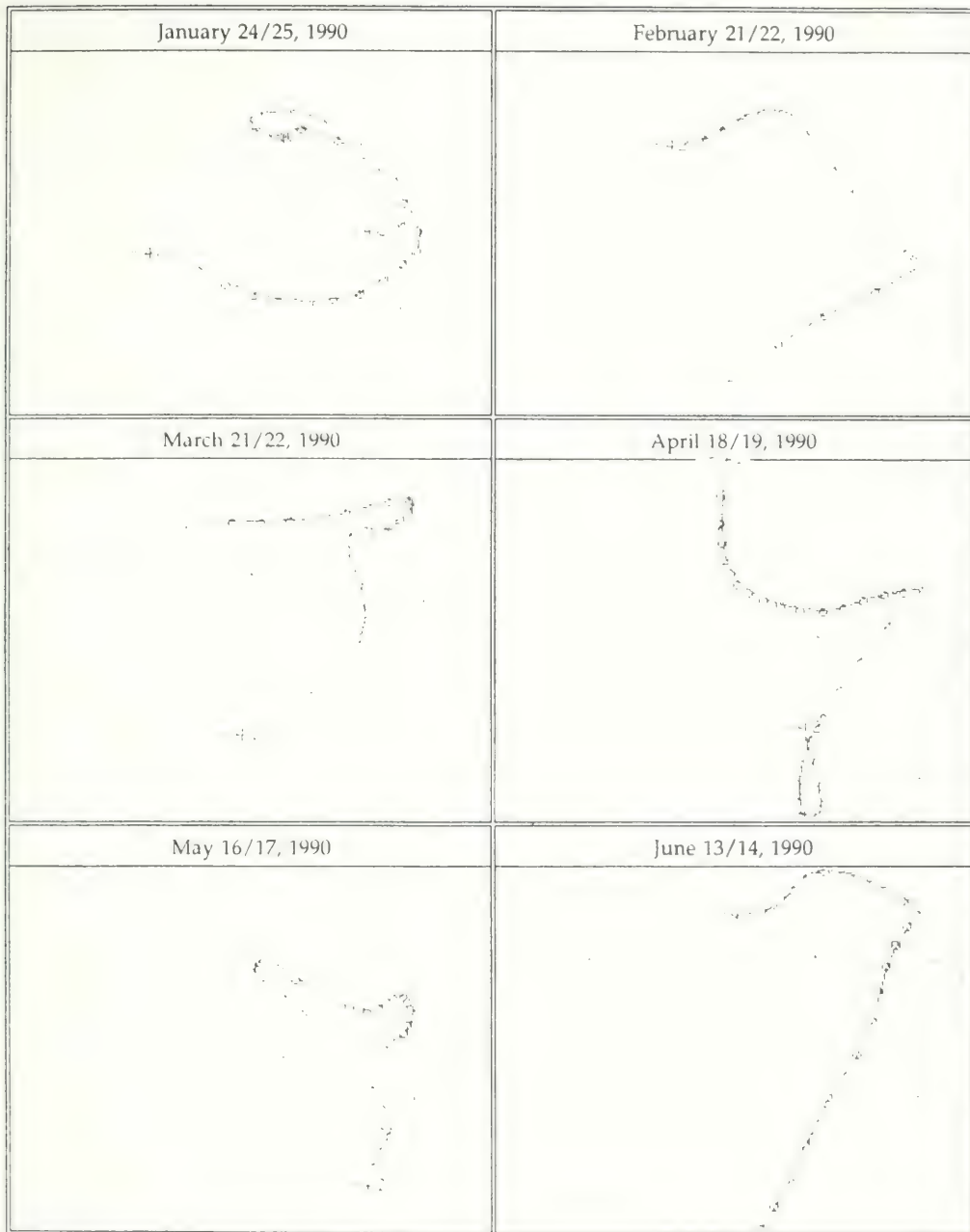


Figure 4. Surface back trajectories for Marathon (first day: -o---o- and second day -x---x-).

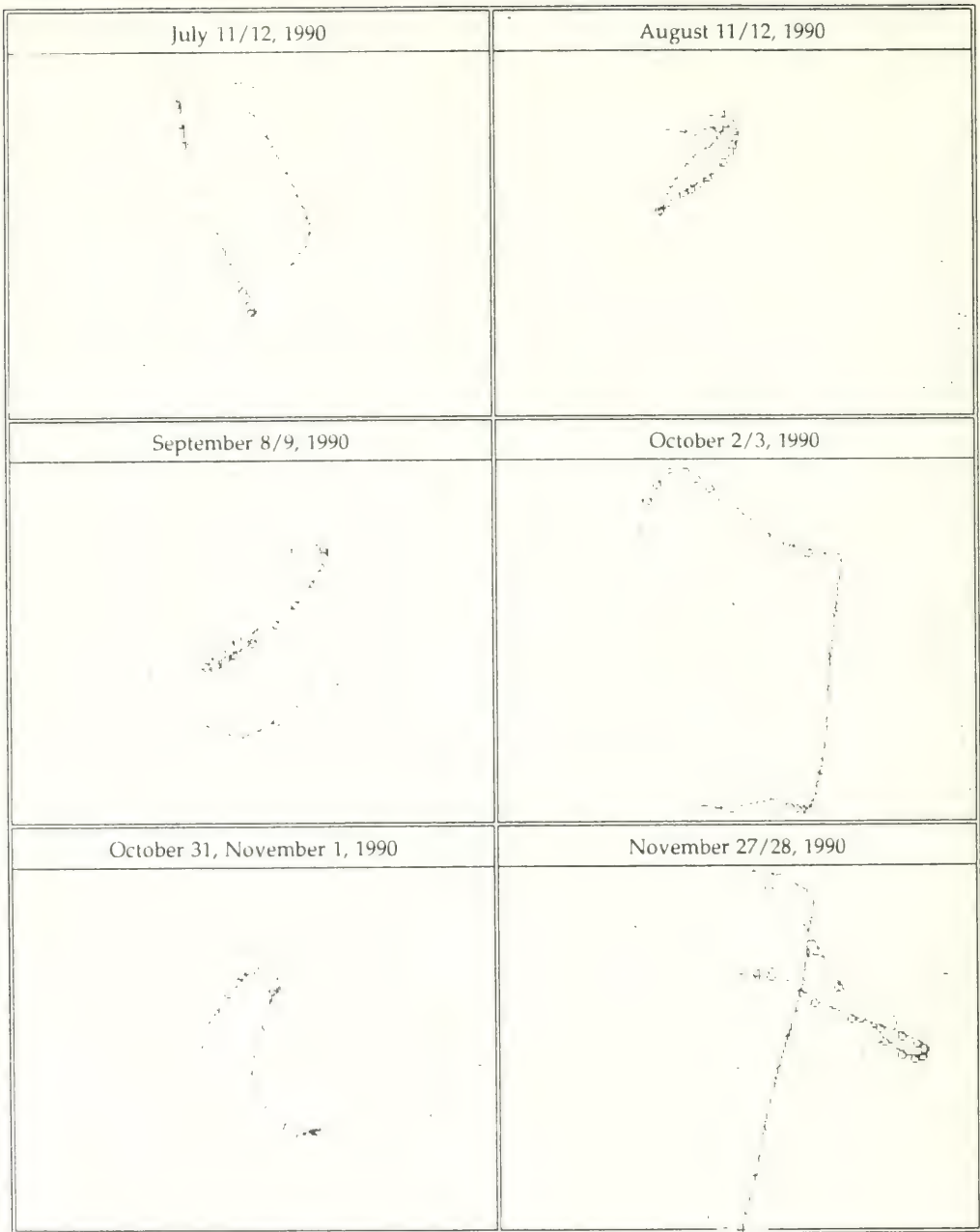


Figure 4. Continued.

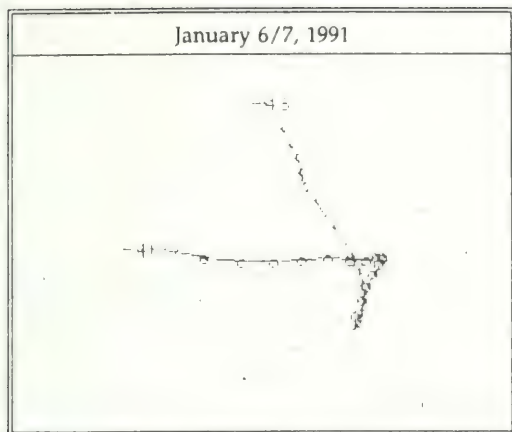


Figure 4. Continued.

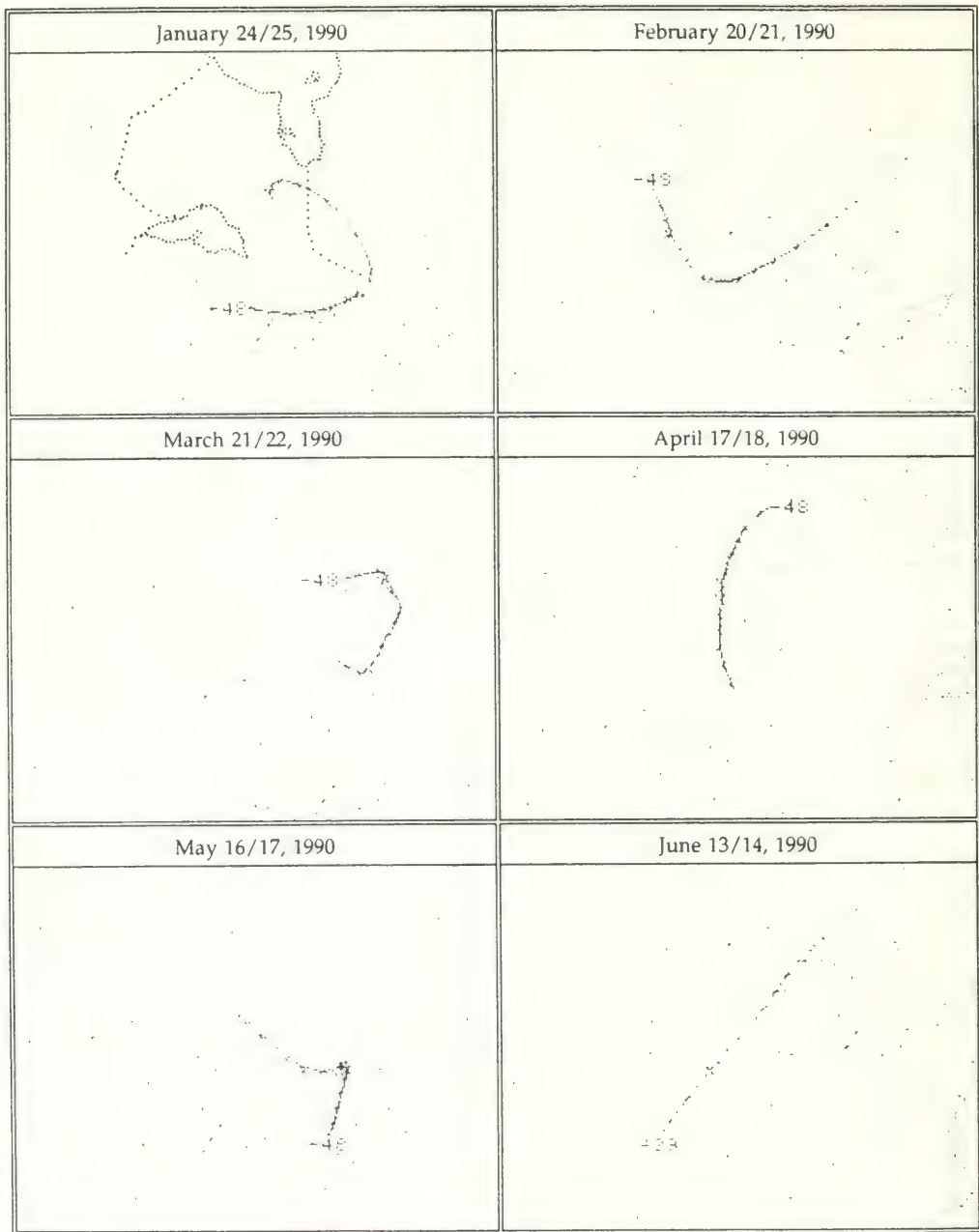


Figure 5. Surface back trajectories for Smooth Rock Falls (second day only).

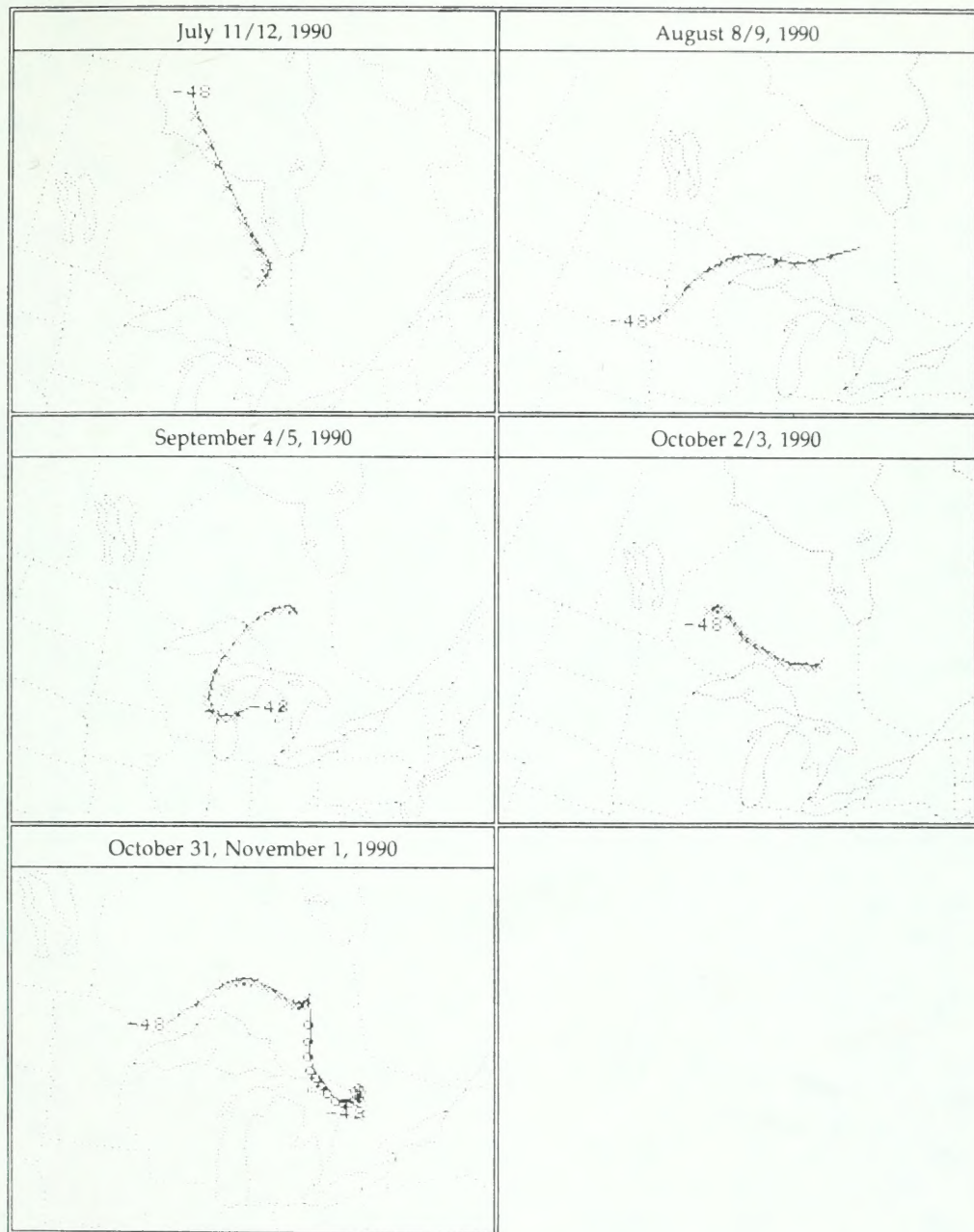


Figure 5. Continued.

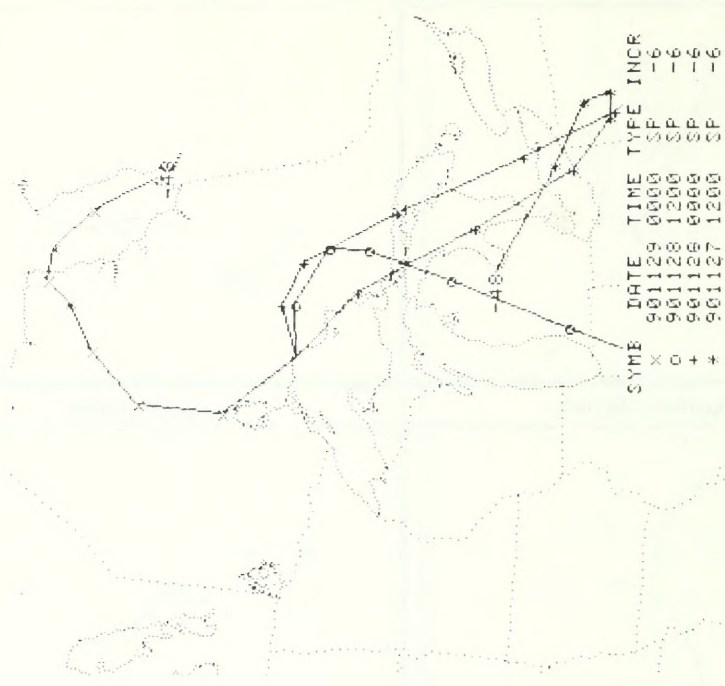
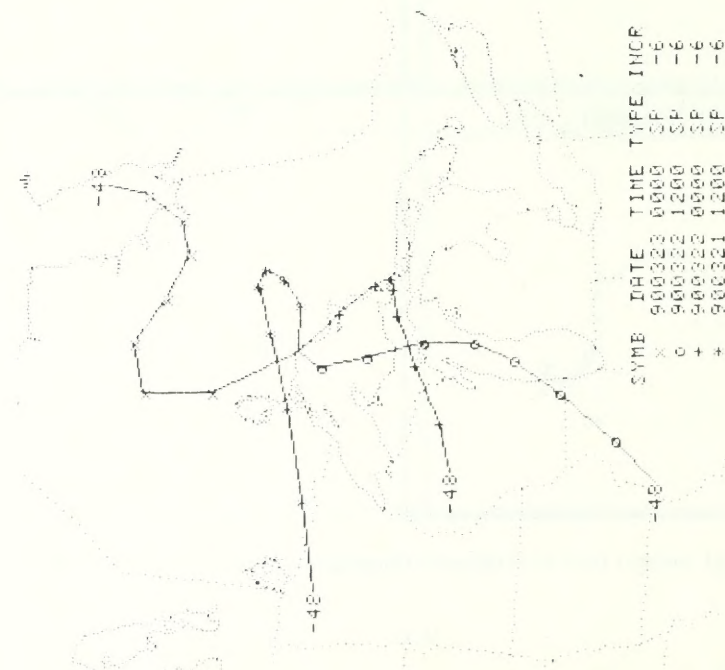


Figure 6. Surface back trajectories for Marathon for four different starting times and two sampling days.



